**Table 9.4.** *Depth-duration relations (percent of 1-hour amount) for 1-$mi^2$ PMP for California local storms.*

| | Relationship Designator (see Figure 9.17) | | | |
|---|---|---|---|---|
| Duration (hours) | A | B | C | D |
| 0 | 0 | 0 | 0 | 0 |
| 1/4 | 55 | 55 | 55 | 55 |
| 1/2 | 79 | 79 | 79 | 79 |
| 3/4 | 91 | 91 | 91 | 91 |
| 1 | 100 | 100 | 100 | 100 |
| 2 | 109.5 | 110.5 | 114 | 117 |
| 3 | 112 | 116 | 120 | 126 |
| 4 | 114 | 118 | 125 | 132 |
| 5 | 114.5 | 119 | 128 | 137 |
| 6 | 115 | 120 | 130 | 140 |

The recommended chronology for incremental local-storm amounts will be mentioned in Chapter 13, Sections 13.4.2 and 13.5.2 to follow.

## 9.9 Depth-Area Relationships

### 9.9.1 Spatial Aspects

One of the most critical aspects of the PMP problem is how the storm varies spatially. Since the index map for local-storm is drawn for a 1 square mile area, it is necessary to develop relationships for areas out to the limits of the storm. Perhaps no segment of PMP research is subject to more uncertainty, owing once again to the almost total lack of reliable data. The small-scale of most intense thunderstorms and the broadly spaced conventional rainfall observing network ensures that these storms will be poorly sampled, if not missed altogether. A relatively few studies using dense rain gage networks have provided insight into the spatial distribution of heavy rainfall in intense convective storms and much of what has been learned comes from these few studies. A review of much of this research can be found in the section on local-storm depth-area relations in HMR 57 and is not repeated here.

In an attempt to look at spatial patterns, the isohyetal patterns from all 137 local storms listed in Table A3.1 (Appendix 3) were plotted. To ensure complete coverage of the storms, the rainfall center and all stations within a 1-degree radius of latitude and longitude were mapped. This provided an area (over 11,000 mi$^2$) of coverage for each storm, well in excess of the rainfall production from any local storm. This proved to be a relatively unproductive exercise, in that the wide spacing of the observing network did not allow for a detailed evaluation of depth-area relationships. In a few cases, with storm centers located in highly populated areas, some spatial patterns could be identified. The mapping of the isohyetal patterns of these storms did provide some rudimentary information on the areal extent of rainfall in these storms, especially at the edges of the rain shield. In many cases the closest gage to the storm center is 20 or more miles away, meaning there is only one observation within the 500 square miles around the center, if in fact the true center has even been measured. If nothing else, the isohyetal patterns in these 137 storms provide support to the concept of the local storm covering an area of up to at least 500 mi$^2$. While the majority cover a lesser area size there are a substantial number with precipitation covering an area of this size or greater. With the poor resolution allowed by the gage spacing it is difficult to determine the *real* isohyetal pattern, but certainly it can inferred to some degree. Storms in Appendix 3 (Table A1.3) that cover an area of at least 500 mi$^2$ include those of August 22, 1951, August 23, 1955, August 4, 1961, August 7, 1963, August 25, 1982, and June 7, 1989. The density of gages in these storms was such that it seems fairly certain that the storms covered an area of at least 500 mi$^2$. In many other cases it was difficult to determine whether observed amounts represent multiple storm centers or if there was a systematic decrease in rainfall away from the nominal storm center. Again, the resolution of the network simply precludes a more detailed and informative analysis.

### 9.9.2 Additional Depth-Area Analysis

The adopted depth-area relationship for this study draws heavily on the few extreme storms that have been thoroughly documented in terms of rainfall distribution. In California the storms include Tehachapi (9/30/32), Vallecito (7/18/55), and Bakersfield (6/7/72). These storms were also available when HMR 49 was prepared and were used in conjunction with other Southwestern United States extreme local storms, to establish a series of depth-area curves (Figure 4.8, page 121 of HMR 49) which were applied to the entire Great Basin and California. The final depth-area curves for HMR 49 for durations from 15 minutes to 6 hours are shown in Figure 4.9 (page 123) of that report. Since HMR 49 was published in 1977, several important storms have occurred in California and other parts of the Southwest which provide some important support to the depth-area relationships contained in that report. In addition, the Hydrometeorology Branch undertook a reanalysis of the depth-area curves for the storms that were used in HMR 49 in an attempt to validate the results of that study.

The new storms analyzed for depth-area relations include the previously discussed Palomar Mountain storm (storm #30 in Table and Figure 9.1), the Borrego storm (#26), and a storm near Ute, Nevada that occurred on August 10, 1981, and does not appear on the California storm list.

The Palomar storm discussed in Section 9.4.3 was also analyzed for depth-area using the published isohyetal pattern in a storm report prepared by the Flood Control Division, County of San Diego (1992). The storm pattern was digitized and a depth-area analysis was determined. The values from the depth-area analysis of the Palomar storm at 4 hours are only slightly larger than those from the HMR 49 depth-area curve for area sizes up to about 50 $mi^2$ and only slightly below at greater area sizes.

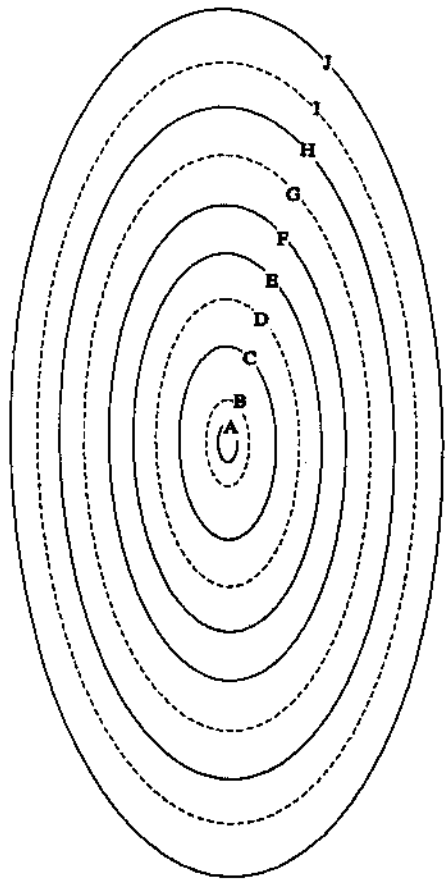
The Ute, Nevada storm, a well-documented MCC in August, 1981 (Randerson 1986) provided strong supporting data for the validity of depth-area relationships found in HMR 49. This storm occurred close enough to California (about 75 miles) for it to be considered transposable to the state. A comparison between the three-hour depth-area pattern from this storm and the three-hour curve in HMR 49 shows that the two patterns are remarkably close for all area sizes out to 500 $mi^2$.

The isohyetal patterns for the storms contained in HMR 49 were re-analyzed for depth-area relationships in order to document their accuracy and homogeneity using digital techniques not available in that study. The storms which were re-analyzed included all seven of those shown in HMR 49, Figure 4.8, three of which were California storms also shown here in Table 9.1. The results were reassuring in that there was little substantial variation between the two sets of analyses for most of the storms, and where there were large differences, the underestimates were in HMR 49. Differences ranging from about 2 percent to 14 percent were found in the Bakersfield storm, with the largest difference at an area size of a little over 10 $mi^2$. Larger departures from the analysis in HMR 49 were found for the Phoenix, Arizona storm of June 22, 1972. Differences of greater than 20 percent were found to occur at some area sizes, the largest at about 100 $mi^2$. It is unclear as to why such discrepancies were found, but the new analysis was performed using the isohyetal pattern contained in the Corps of Engineers study of October 1972 (USCOE 1972), which is the most definitive study on this storm.

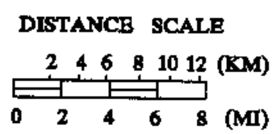
### 9.9.3 Areal Distribution Procedure

The first step in this procedure is to set the rainfall pattern for the local storm. That is, both the shape of the pattern and its distribution (number and gradient of isohyets) need to be fixed. For this study, there are four distinctive local-storm distributions corresponding to the four distinct groups of 6-hour to 1-hour depth-duration ratios found for California local storms discussed in Section 9.8. The isohyetal pattern shown in Figure 9.18 is considered to be representative of the pattern for each of the four groups of local storms. The assigned isohyetal values are specified by the percentages shown in Tables 9.5 to 9.8. These gradient specifying values illustrate the transition from the characteristic northwest states local-storm model in HMR 57 to the local-storm model valid for the Colorado River and Great Basin drainages in HMR 49.

Given the 2 to 1 ratio of major to minor axis of the elliptical isohyetal local-storm pattern in Figure 9.18 and the four sets of rainfall gradient specifying values, it is a straightforward matter to calculate the average depth-area relationship necessary to produce the isohyetal labels shown in Tables 9.5 to 9.8. The results from these calculations are shown in Tables 9.9 to 9.12 and are also shown in graphical form in Figures 9.19 to 9.22. Tables 9.9 to 9.12 are not reproduced in Chapter 13 since Figures 13.25 to 13.28 contain all the information necessary to make depth-area adjustments. The use of these tables and figures is outlined in Chapter 13, the local-storm procedure.




| | ENCLOSED AREA | |
|---|---|---|
| | AREA | |
| ISOHYET | $(MI^2)$ | $(KM^2)$ |
| A | 1 | 2.6 |
| B | 5 | 13 |
| C | 25 | 65 |
| D | 55 | 142 |
| E | 95 | 246 |
| F | 150 | 388 |
| G | 220 | 570 |
| H | 300 | 777 |
| I | 385 | 997 |
| J | 500 | 1295 |




SCALE
1:500,000

**Figure 9.18.** *Idealized isohyetal pattern for local-storm PMP areas up to 500 mi$^2$. Same as Figure 13.20.*

**Table 9.5.** *Isohyetal label values (percent of 1-hour, 1-mi² average depth) to be used with the isohyetal pattern of Figure 9.18 and basin average depths from Figure 9.19.*

| | Duration (hours) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Isohyet | 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
| A | 55 | 79 | 91 | 100 | 109.5 | 112 | 114 | 114.5 | 115 |
| B | 35 | 57 | 68 | 74.8 | 83.5 | 85.5 | 87.5 | 88 | 88.5 |
| C | 24 | 40 | 49 | 56 | 62.9 | 4.5 | 66 | 66.5 | 67 |
| D | 18.5 | 30.5 | 39 | 43 | 48 | 49.5 | 50.6 | 51.1 | 51.5 |
| E | 13 | 22.5 | 29 | 32.2 | 36.6 | 37.7 | 38.6 | 39 | 39.5 |
| F | 7.5 | 14.0 | 19 | 22.4 | 25 | 25.7 | 26.3 | 26.7 | 27.0 |
| G | 4.5 | 8.5 | 12 | 14.0 | 16.2 | 16.8 | 17.4 | 17.9 | 18.2 |
| H | 1.8 | 3.5 | 5 | 6.5 | 8.3 | 8.8 | 9.3 | 9.8 | 10.3 |
| I | 0.4 | 0.7 | 0.9 | 1.1 | 2.2 | 2.7 | 3.2 | 3.7 | 4.1 |
| J | 0.1 | 0.3 | 0.5 | 0.7 | 1.2 | 1.7 | 2.2 | 2.6 | 2.9 |

**Table 9.6.** *Isohyetal label values (percent of 1-hour, 1-mi² average depth) to be used with the isohyetal pattern of Figure 9.18 and the basin average depths from Figure 9.20.*

| | Duration (hours) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Isohyet | 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
| A | 55 | 79 | 91 | 100 | 110.5 | 116 | 118 | 119 | 120 |
| B | 35.5 | 55 | 68 | 78 | 88 | 95 | 99 | 101 | 102.5 |
| C | 24 | 39 | 49 | 57 | 66 | 72 | 75 | 77 | 78.5 |
| D | 19 | 30 | 39 | 44 | 51.5 | 56 | 58.5 | 60 | 61 |
| E | 13.5 | 22 | 28 | 33 | 39 | 42.7 | 44.5 | 46 | 47 |
| F | 8.5 | 15 | 20 | 23 | 28 | 31.5 | 33.5 | 35 | 36 |
| G | 5.5 | 9.5 | 13 | 15 | 19 | 22 | 24 | 25 | 26 |
| H | 2 | 4.5 | 6.0 | 7.5 | 11.5 | 14.5 | 16.5 | 17.5 | 18.5 |
| I | 1 | 2 | 3 | 4 | 8 | 11 | 13 | 14.5 | 15.5 |
| J | 1 | 2 | 3 | 4 | 7 | 10 | 12 | 13.5 | 14.5 |

**Table 9.7.** *Isohyetal label values (percent of 1-hour, 1-mi² average depth) to be used with the isohyetal pattern of Figure 9.18 and the basin average depths from Figure 9.21.*

| | Duration (hours) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Isohyet | 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
| A | 55 | 79 | 91 | 100 | 114 | 120 | 125 | 128 | 130 |
| B | 44 | 66 | 77.6 | 86 | 100 | 106 | 111 | 114 | 116 |
| C | 26 | 44 | 53.6 | 61 | 74 | 81 | 86 | 89 | 91 |
| D | 17 | 31 | 40.2 | 46.5 | 58 | 65 | 70 | 73 | 75 |
| E | 11 | 20 | 26.8 | 32.5 | 42 | 49 | 54 | 57 | 59 |
| F | 6.6 | 13 | 19 | 24 | 32 | 38 | 43 | 46 | 48 |
| G | 6.5 | 11 | 14 | 16 | 23 | 28 | 33 | 36 | 38 |
| H | 5 | 8 | 10.5 | 12 | 17.5 | 21.5 | 25.5 | 29 | 31 |
| I | 3 | 6.0 | 8.5 | 10.5 | 16 | 20 | 24 | 27.5 | 30 |
| J | 2.5 | 5.5 | 8 | 10 | 15 | 19 | 23 | 26.5 | 29 |

**Table 9.8.** *Isohyetal label value (percent of 1-hour, 1-mi² average depth) to be used with the isohyetal pattern of Figure 9.18 and the basin average depths from Figure 9.22.*

| | Duration (hours) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Isohyet | 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
| A | 55 | 79 | 91 | 100 | 117 | 126 | 132 | 137 | 140 |
| B | 39 | 61 | 74 | 84 | 100 | 109 | 115 | 120 | 123 |
| C | 24 | 42 | 52 | 60 | 76 | 85 | 91 | 96 | 99 |
| D | 15 | 28 | 37 | 44 | 59 | 67 | 73 | 78 | 81 |
| E | 9 | 19 | 26 | 32 | 44 | 52 | 58 | 63 | 67 |
| F | 6 | 13.5 | 19 | 24 | 34 | 40 | 45 | 50 | 54 |
| G | 6 | 10 | 13.5 | 16 | 24 | 30 | 35 | 39 | 42 |
| H | 4 | 7 | 10 | 13 | 19 | 24 | 28 | 32 | 35.5 |
| I | 3.3 | 6.5 | 9 | 11 | 18 | 23 | 27 | 31 | 34.5 |
| J | 3 | 5.5 | 8 | 10 | 17 | 22 | 26 | 30 | 33.5 |

**Table 9.9.** *Average depth of local-storm PMP (percent of 1-mi² average depth) for area size and duration where the 6-hour to 1-hour, 1-mi² depth-duration ratio is less than 1.2.*

| Area (mi²) | Duration (hours) 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 5 | 85.4 | 88.8 | 89.8 | 90.0 | 90.4 | 90.5 | 90.7 | 90.8 | 90.8 |
| 25 | 60.0 | 66.8 | 69.3 | 70.4 | 71.3 | 71.7 | 72.0 | 72.2 | 72.3 |
| 55 | 48.3 | 54.8 | 57.9 | 59.0 | 59.9 | 60.3 | 60.6 | 60.8 | 61.0 |
| 95 | 40.0 | 45.8 | 49.2 | 50.0 | 50.9 | 51.3 | 51.6 | 51.8 | 52.0 |
| 150 | 32.4 | 37.7 | 40.9 | 41.7 | 42.5 | 42.9 | 43.1 | 43.3 | 43.5 |
| 220 | 25.9 | 30.6 | 33.3 | 34.2 | 34.9 | 35.3 | 35.5 | 35.7 | 35.9 |
| 300 | 20.7 | 24.6 | 27.0 | 27.8 | 28.6 | 28.9 | 29.2 | 29.4 | 29.6 |
| 385 | 16.6 | 19.8 | 21.7 | 22.5 | 23.3 | 23.7 | 23.9 | 24.2 | 24.5 |
| 500 | 12.9 | 15.4 | 16.9 | 17.5 | 18.3 | 18.7 | 19.0 | 19.3 | 19.6 |

**Table 9.10.** *Average depth of local-storm PMP (percent of 1-mi² average depth) for area size and duration where the 6-hour to 1-hour, 1-mi² depth-duration ratio of 1.2.*

| Area (mi²) | Duration (hours) 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 5 | 85.8 | 87.9 | 89.9 | 91.2 | 92.0 | 92.8 | 93.6 | 94.0 | 94.2 |
| 25 | 60.3 | 65.2 | 69.4 | 72.2 | 74.4 | 76.2 | 77.8 | 78.6 | 79.2 |
| 55 | 48.1 | 53.3 | 57.8 | 60.4 | 62.9 | 64.7 | 66.2 | 67.1 | 67.7 |
| 95 | 39.7 | 44.6 | 48.9 | 51.2 | 53.8 | 55.4 | 56.7 | 57.6 | 58.1 |
| 150 | 32.1 | 36.7 | 40.6 | 42.7 | 45.2 | 46.8 | 48.0 | 48.9 | 49.5 |
| 220 | 25.7 | 29.9 | 33.4 | 35.1 | 37.7 | 39.3 | 40.5 | 41.4 | 42.0 |
| 300 | 20.6 | 24.3 | 27.3 | 28.8 | 31.3 | 33.0 | 34.3 | 35.1 | 35.7 |
| 385 | 16.6 | 19.8 | 22.3 | 23.7 | 26.4 | 28.1 | 29.5 | 30.3 | 31.0 |
| 500 | 13.2 | 15.8 | 18.0 | 19.2 | 21.9 | 23.8 | 25.1 | 26.1 | 26.7 |

**Table 9.11.** *Average depth of local-storm PMP (percent of 1-mi² average depth) for area size and duration where the 6-hour to 1-hour, 1-mi² depth-duration ratio of 1.3.*

| Area (mi²) | Duration (hours) 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 5 | 92.0 | 93.4 | 94.1 | 94.4 | 95.1 | 95.3 | 95.5 | 95.6 | 95.7 |
| 25 | 69.3 | 74.4 | 76.5 | 77.7 | 80.1 | 81.4 | 82.1 | 82.6 | 82.8 |
| 55 | 52.8 | 59.7 | 62.9 | 64.6 | 68.0 | 70.2 | 71.4 | 72.0 | 72.5 |
| 95 | 41.3 | 48.2 | 51.9 | 54.0 | 57.9 | 60.6 | 62.2 | 63.1 | 63.7 |
| 150 | 32.0 | 38.2 | 42.1 | 44.6 | 48.6 | 51.7 | 53.6 | 54.7 | 55.4 |
| 220 | 25.2 | 30.6 | 34.4 | 36.8 | 40.8 | 44.0 | 46.2 | 47.5 | 48.3 |
| 300 | 20.7 | 25.3 | 28.7 | 30.7 | 34.7 | 37.8 | 40.1 | 41.6 | 42.5 |
| 385 | 17.4 | 21.5 | 24.6 | 26.4 | 30.3 | 33.2 | 35.7 | 37.3 | 38.3 |
| 500 | 14.3 | 18.1 | 20.9 | 22.7 | 26.4 | 29.3 | 31.8 | 33.6 | 34.7 |

**Table 9.12.** *Average depth of local-storm PMP (percent of 1-mi² average depth) for area size and duration where the 6-hour to 1-hour, 1-mi² depth-duration ratio of 1.4.*

| Area (mi²) | Duration (hours) 1/4 | 1/2 | 3/4 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 5 | 88.4 | 90.9 | 92.5 | 93.6 | 94.2 | 94.6 | 95.5 | 95.6 | 95.7 |
| 25 | 63.5 | 70.3 | 73.9 | 76.3 | 79.0 | 81.4 | 82.1 | 82.6 | 82.8 |
| 55 | 45.2 | 56.1 | 60.2 | 63.1 | 67.4 | 70.2 | 71.4 | 72.0 | 72.5 |
| 95 | 33.1 | 45.0 | 49.4 | 52.5 | 57.5 | 60.6 | 62.2 | 63.1 | 63.7 |
| 150 | 26.0 | 35.8 | 40.3 | 43.5 | 48.7 | 51.7 | 53.6 | 54.7 | 55.4 |
| 220 | 20.9 | 28.8 | 33.0 | 36.0 | 41.1 | 44.0 | 46.2 | 47.5 | 48.3 |
| 300 | 17.3 | 23.8 | 27.5 | 30.3 | 35.0 | 37.8 | 40.1 | 41.6 | 42.5 |
| 385 | 14.7 | 20.3 | 23.7 | 26.3 | 30.8 | 33.2 | 35.7 | 37.3 | 38.3 |
| 500 | 12.4 | 17.2 | 20.3 | 22.6 | 27.1 | 29.3 | 31.8 | 33.6 | 34.7 |

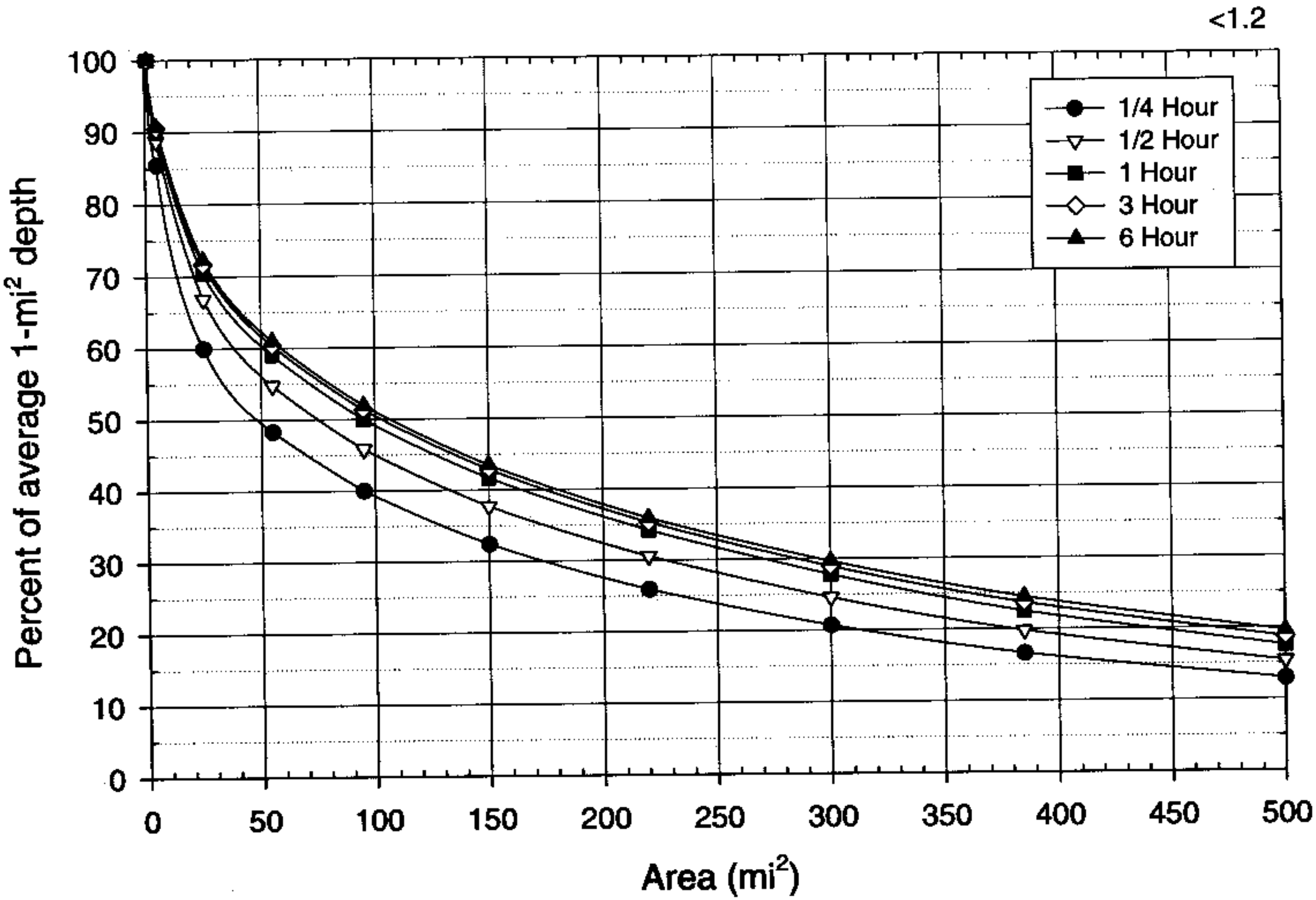



**Figure 9.19.** *Depth-area relations for California local-storm PMP for a 1-mi², 6-hour, to 1-hour depth-duration ratio less than 1.2. Same as Figure 13.25.*

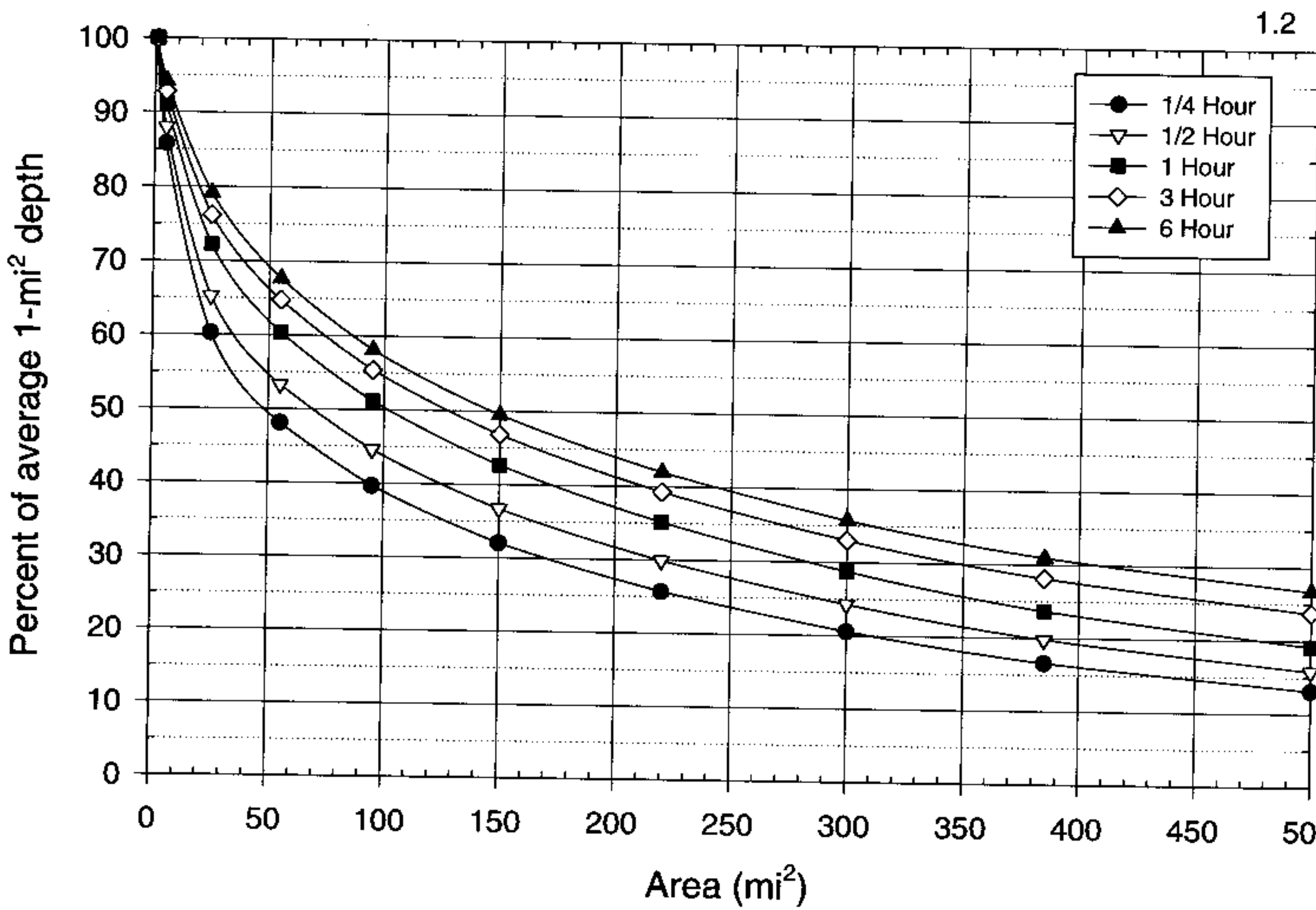



**Figure 9.20.** *Depth-area relations for California local-storm PMP for a 1-mi², 6-hour, to 1-hour depth-duration ratio equal to 1.2. Same as Figure 13.26.*

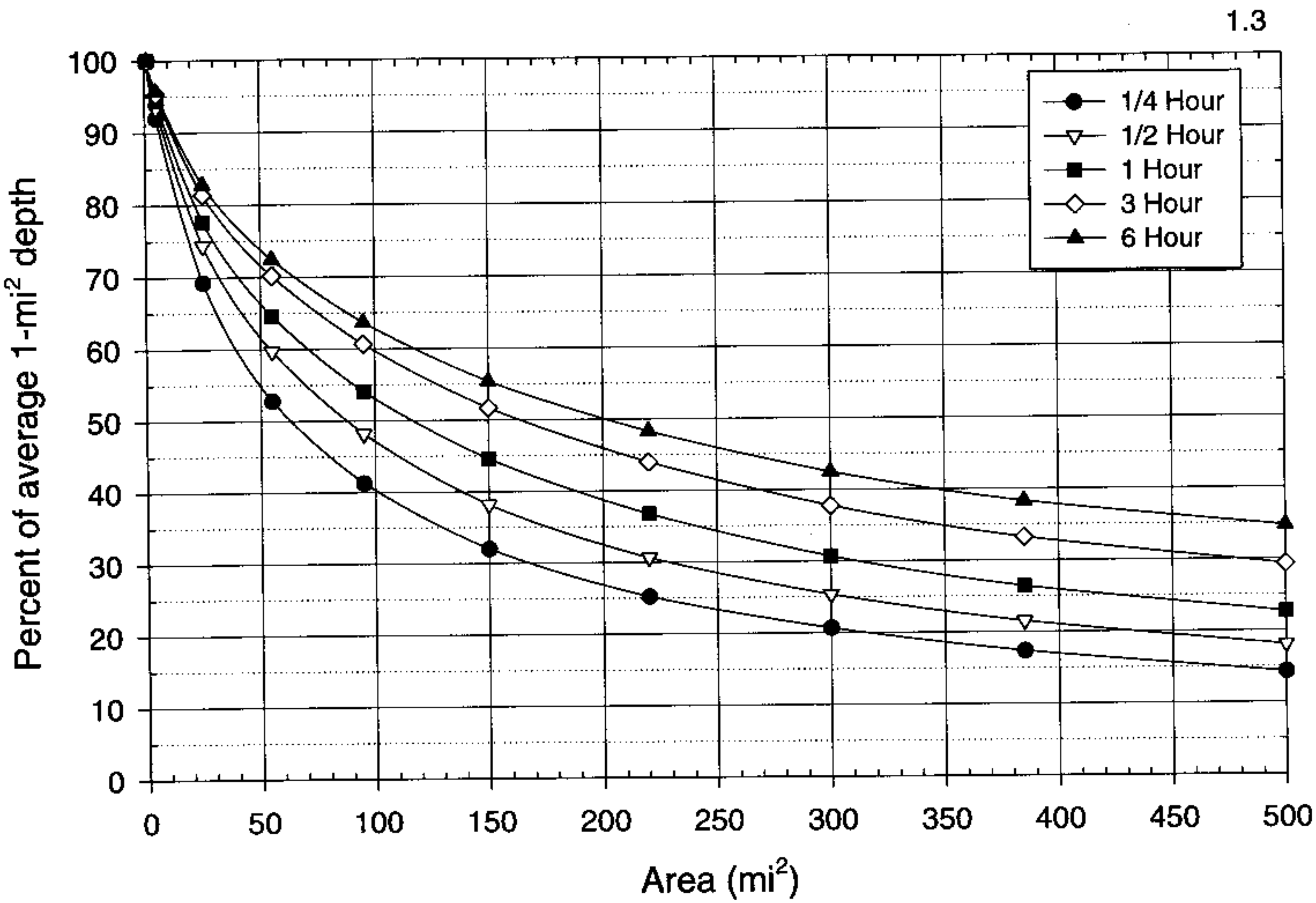



**Figure 9.21.** *Depth-area relations for California local-storm PMP for a 1-mi$^2$, 6-hour, to 1-hour depth-duration ratio equal to 1.3. Same as Figure 13.27.*

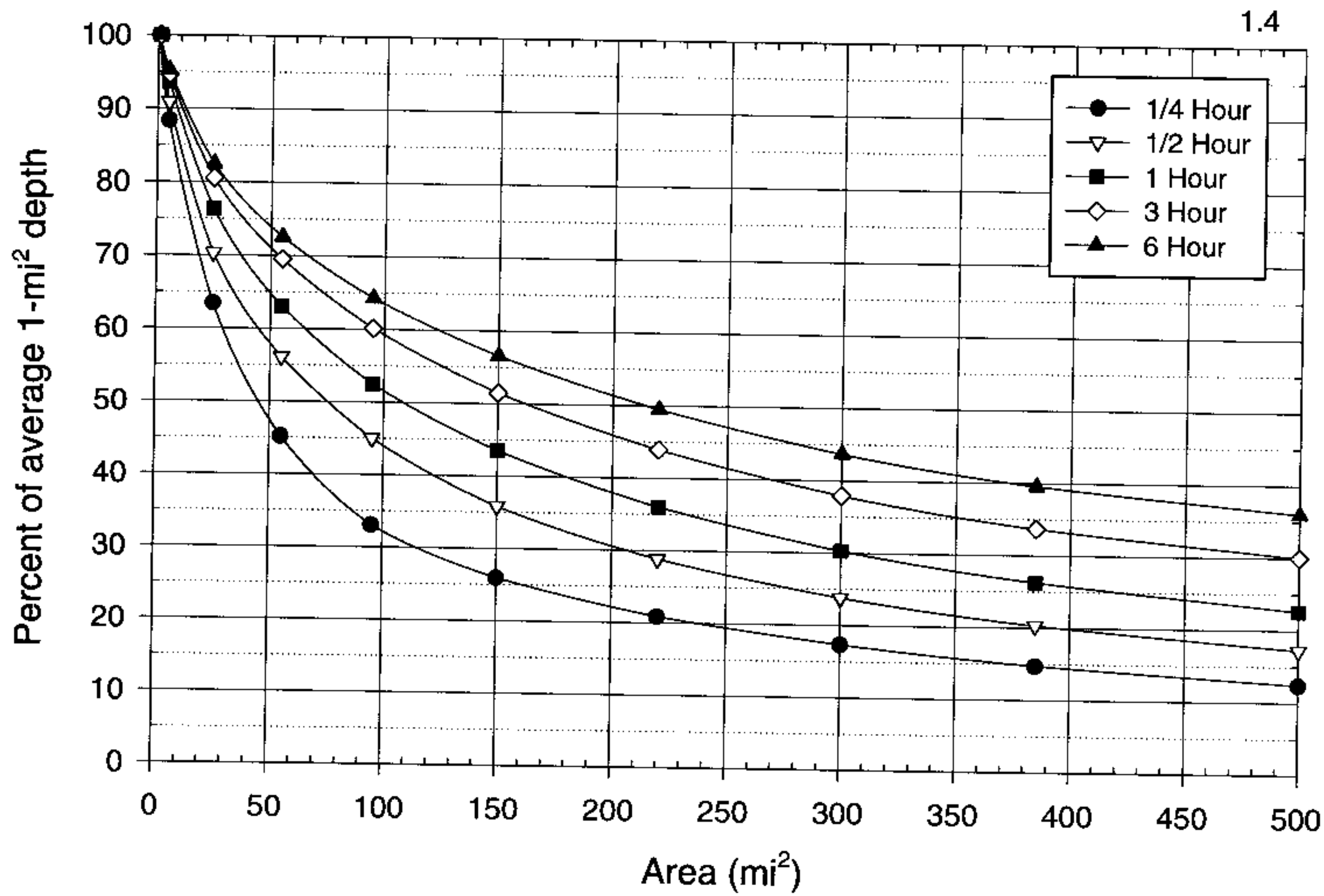



**Figure 9.22.** *Depth-area relations for California local-storm PMP for a 1-mi², 6-hour, to 1-hour depth-duration ratio equal to 1.4. Same as Figure 13.28.*

## 9.10 Local-storm Index Maps

The local storm or 1-hour, 1-$mi^2$ PMP Index map, shown in Figure 9.23, used the HMR 49 Index map as a starting point. As discussed in Section 9.3, 14 storms were added to the extreme storm list since HMR 49. As obviously the terrain is unchanged, any new storms and changes in the way the moisture field was drawn (the basis for storm maximization) would provide justification for Index map changes.

The Index map shows a PMP maximum of 12 inches over southern California, including much of the Imperial Valley and adjacent mountains to the west. The preponderance of extreme storms in this part of the state (Figure 9.1) provides strong evidence that it is a favored location for the development of intense storms. Proximity to the rich moisture source of the Gulf of California, a southerly latitude allowing for maximum solar insolation, a tendency for low-level jets to form in this area, and the possibility of mesoscale systems to propagate westward out of Arizona into this region (e.g., the Palomar Mountain storm) are all factors for heavy rainfall event occurrence in this area.

A much more widespread maximum of more than 11 inches covers the desert area of southern and southeastern California, with the 11-inch isoline bulging northwest into the San Bernardino Mountains east of Los Angeles. Again, this entire area is open to periodic incursions of subtropical moisture from the Gulf of California or Pacific Ocean. The rare hurricanes, tropical storms or more likely their remnants, into this part of California is a major source of heavy rainfall during these infrequent events (e.g., the Indio storm of September 1939 or the Borrego storm of September 1976).

Local-storm PMP decreases rather sharply along the coastal plain of southern California, falling to around 7 inches in the San Diego and Los Angeles metropolitan areas, a value only about 55 to 65 percent of that in the mountains only a short distance away. This dramatic change indicates the importance of terrain in helping to initiate convection and in anchoring some storms in stationary positions, which can lead to very heavy local rainfall. The Palomar Mountain storm is an excellent example of this type of terrain influence on extreme storm formation and maintenance. The extreme storms that do occur

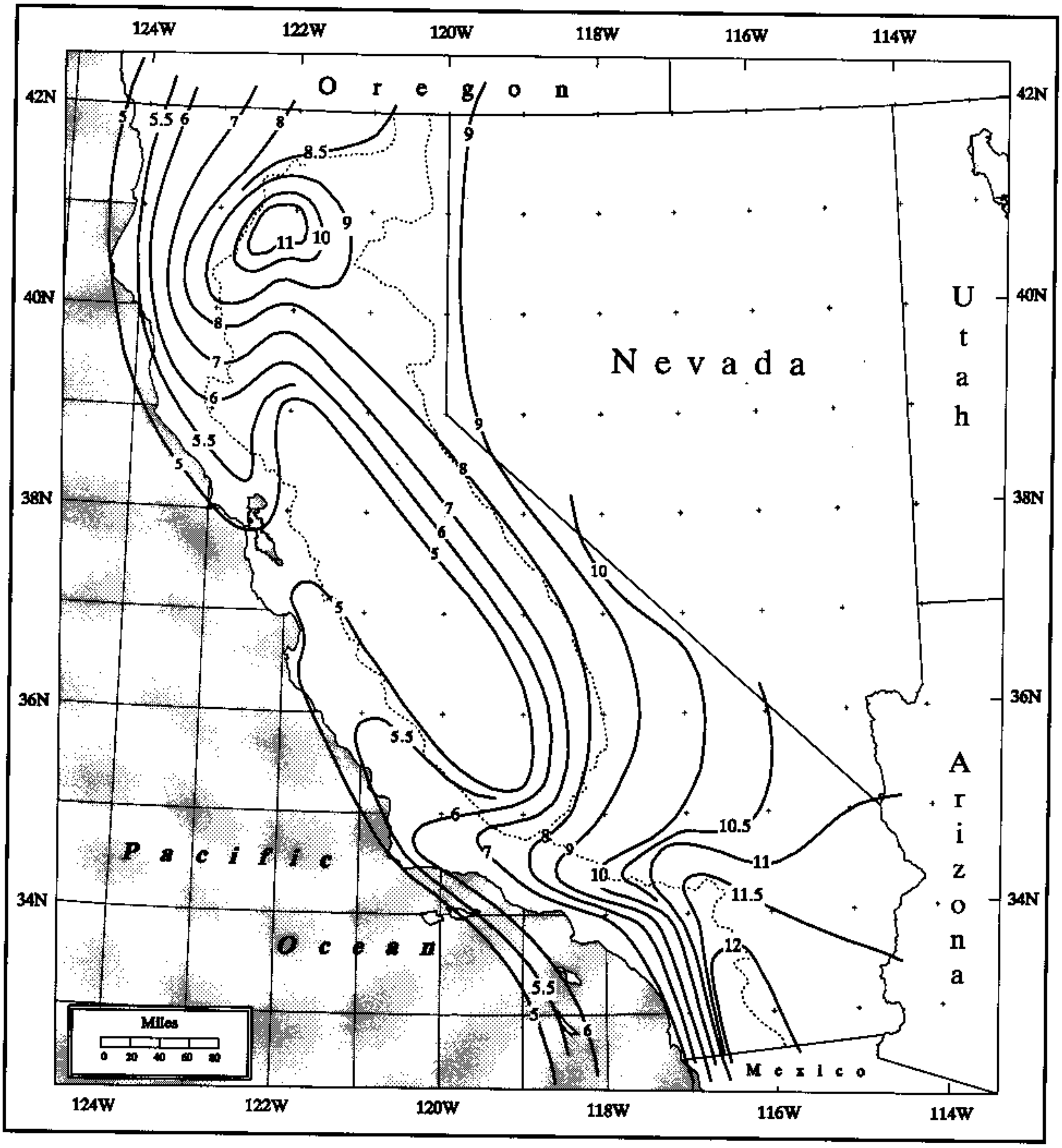



**Figure 9.23.** *California local-storm PMP precipitation estimates for 1 mi², 1 hour (inches). Dashed lines are drainage divides. Same as Figure 13.21.*

along the coast are more often the result of embedded convection within mesoscale rainbands in large-scale storms. Good examples are both Santa Barbara storms of February 1958 and January 1978.

Moving north and west from the southern California mountains, PMP continues to decrease steadily, reaching a broad minimum over the Central Valley. PMP within this broad, flat area is about only about 5 inches, for reasons that are primarily terrain-related. Moisture inflow is sharply limited from the southeast, where the highest moisture sources exist and also from the west where the coastal ranges block Pacific Ocean air from reaching the Valley easily, except for a small opening through the San Francisco Bay area. In addition, no natural terrain features exist to enhance uplift or channel the moisture flows within the valley itself.

A secondary PMP maximum of 11 inches is found over the northern end of the Sacramento River valley and in the adjacent high terrain near Shasta Lake. One of the factors involved in the existence of this PMP center includes the frequent development of a low-level jet which transports moisture northward very efficiently. In addition, the terrain is also favorable for storm development. The Valley narrows near its northern end, causing increased local convergence and uplift, and elevations increase abruptly in the foothills surrounding the upper end of the Valley. Ample extreme storm evidence supports the location of this maximum (Figure 9.1), including the relatively recent Redding storm, discussed in Section 9.4.1.

## 9.11 Comparisons with Previous Work

PMP updates have used the results from earlier antecedent studies as a basis for evaluating newer results. For local-storm PMP in California the only antecedent study was HMR 49, so comparisons are obviously limited. However, a comparison was also made with HMR 57 along the Oregon-California border. As a first step in the comparison, both HMR 49, Figure 4.5 and the new local-storm PMP Index maps, Figure 9.23, were digitized and a raster field generated for each. The results showed that the largest differences between HMR 49 and the new local-storm Index map are concentrated in the northwestern part of California, mostly in the Eel and Russian River basins. Increases of up to 30 percent occur over a very small part of that area, but a more general increase of 10 to 15 percent is found over most of California north of about 40°N latitude. Over most of the state the ratio between the two maps is actually quite close to one (i.e., no difference), falling within plus or minus 5 percent. In a few isolated spots, the percentage is around 90, and a broad area of 95 percent or less occurs over the Mojave Desert and surrounding areas.

Individual basin comparisons were also carried out for 50 basins across the state, ranging in size from less than 1 $mi^2$ up to nearly 500 $mi^2$. These basin comparisons were carried out for both the 1- and 6-hour durations. The most important differences occur at the 6-hour duration, which was expected since the depth-duration ratios in HMR 49 were lowered, quite significantly in some parts of the state (Section 9.9 - Depth-Duration Relationships). At 1-hour, the basin PMP differences are fairly limited, with the variations reflecting the pattern discussed above. As an example, for Santa Monica Creek, a small basin near the coast, the HMR 49 PMP was 94 percent of the new PMP at 1 hour (5.67 inches versus 6.05 inches). At 6 hours, however, the HMR 49 PMP was 123 percent of the new PMP (10.06 inches versus 8.20 inches). Numerous test basins showed a similar pattern of close agreement at the 1-hour duration, with much wider differences at 6 hours.

Another comparison was made along the Oregon-California border where the new local-storm Index map, Figure 9.23, joins the HMR 57 Index map. Here, the differences are slight, amounting to less than a half inch at the intersection of the California coast and the border of Oregon (5.1 inches in Figure. 9.23 vs. 5.5 inches in HMR 57 Figure 11.19). The differences decrease steadily to the east, reaching essentially zero at the northeast corner of California. The new values are consistently just slightly lower than the HMR 57 values, until the difference reaches zero. Considering that the same methodology and the same major storm data base was available for both studies, the reason for these minor differences may be ascribed to the slight variation in the 3-hour maximum-persisting dewpoint fields between the two studies (Section 9.5.1). This difference resulted in a lower storm maximization in the current California study than in HMR 57, thus causing the border discrepancies. Since the elevation and depth-duration relationships for this study are the same as those in HMR 57 no greater deviations between the two reports may be expected to occur at the 6-hour time frame or in high elevation basins.

# 10. INDIVIDUAL DRAINAGE PMP COMPARISONS

An important final step was to compare probable maximum precipitation (PMP) estimates for individual drainages from the present study, HMR 59, with those defined in HMR 36 (1961). Many differences, some quite profound, have appeared and thus, have reflected the need for the new data and revised methodologies. Some of the changes will have an immediate impact on present and future water control projects.

Thirty eight basins which were examined to compare HMR 59 PMP estimates to HMR 36 PMP values. Table 10.1 shows the results for each basin, listed in order of increasing basin size. The basins are shown on the map, Figure 10.1. All of the basins drain, at least partially, from mountainous regions and are impacted by orographic precipitation. Most PMP estimates from the smaller basins (less than 200 $mi^2$) have increased substantially from HMR 36 at all durations, to HMR 59. For example, Los Banos Basin, 156 $mi^2$, shows an increase of 22 percent at 6 hours and an increase of 39.7 percent at 72 hours. Basins of 200 $mi^2$ and 1000 $mi^2$ trend toward decreasing PMP values, in relation to HMR 36. Generally, at short durations (1, 6, 12 hours) PMP values have increased and at longer durations (24, 48, 72 hours) PMP values have remained constant or decreased in most instances. In basins greater than 1000 $mi^2$, HMR 59 PMP values decrease substantially as compared with HMR 36 PMP values. For instance, the basin PMP above Twitchell Dam, 1135 $mi^2$, decreases from 22.5 percent at 12 hours to 31.9 percent less than HMR 36 at 24 hours.

Differences in PMP values between the two reports relate to the differences in how the depth-area-duration (DAD) relations were determined. HMR 59 DADs were based upon storm-based relations, whereas, HMR 36 DADs were based upon a mass-conservation model combining air speed, wind direction and resulting moisture off the Pacific. Table 10.2 provides an overall comparison of the percentage changes in general-storm PMP between values computed for this study versus those values determined in HMR 36.

| **Table 10.1.** | *Comparison of various California basin-average PMP depths (inches) from HMR 59 to HMR 36 for selected durations. Associated percentage changes also shown.* |
|---|---|

| Site | $mi^2$ | Study | 1 hr | 6 hr | 12 hr | 24 hr | 48 hr | 72 hr |
|---|---|---|---|---|---|---|---|---|
| Ortega | .0063 | HMR 59 | 3.08 | 10.56 | 16.72 | 22.00 | 31.02 | 34.98 |
| | | HMR 36 | 3.22 | 9.73 | 15.13 | 22.49 | 31.22 | 36.29 |
| | | % change | -4.30 | 8.50 | 10.50 | -2.20 | -0.60 | -3.60 |
| Lauro | 0.44 | HMR 59 | 3.64 | 12.48 | 19.76 | 26.00 | 36.66 | 41.34 |
| | | HMR 36 | 3.20 | 9.61 | 14.94 | 22.21 | 30.83 | 35.84 |
| | | % change | 13.80 | 29.90 | 32.30 | 17.10 | 1.89 | 15.30 |
| Glen Anne | 0.55 | HMR 59 | 3.71 | 12.72 | 20.14 | 26.50 | 37.37 | 42.14 |
| | | HMR 36 | 3.08 | 8.90 | 13.64 | 20.02 | 27.56 | 31.07 |
| | | % change | 20.40 | 42.90 | 47.70 | 32.40 | 35.60 | 35.60 |
| Contra Loma | 1.07 | HMR 59 | 1.82 | 5.88 | 9.10 | 14.00 | 20.72 | 24.50 |
| | | HMR 36 | 2.28 | 5.69 | 8.20 | 11.47 | 15.40 | 18.01 |
| | | % change | -20.20 | 3.30 | 11.00 | 22.10 | 34.50 | 36.00 |
| Sly Park | 17 | HMR 59 | 2.83 | 8.54 | 13.26 | 20.52 | 32.15 | 36.49 |
| | | HMR 36 | 2.19 | 6.69 | 10.64 | 16.61 | 24.50 | 29.46 |
| | | % change | 29.20 | 27.70 | 24.60 | 23.50 | 31.20 | 23.90 |
| Casitas | 39 | HMR 59 | 3.76 | 12.96 | 20.78 | 27.55 | 39.35 | 44.89 |
| | | HMR 36 | 3.25 | 10.91 | 17.48 | 26.63 | 37.50 | 43.69 |
| | | % change | 5.70 | 18.80 | 18.90 | 3.50 | 4.90 | 2.70 |
| Sutherland | 50 | HMR 59 | 2.64 | 9.10 | 14.64 | 19.39 | 27.79 | 31.68 |
| | | HMR 36 | ----- | 10.06 | 16.22 | 24.60 | 34.23 | 39.37 |
| | | % change | | -9.50 | -9.70 | -21.20 | -18.80 | -19.50 |
| San Vincente | 76 | HMR 59 | 1.72 | 5.98 | 9.59 | 12.82 | 18.40 | 20.96 |
| | | HMR 36 | ----- | 6.89 | 10.57 | 15.37 | 20.92 | 24.17 |
| | | % change | | -13.20 | -9.30 | -16.60 | -12.00 | -13.30 |
| Little Panoche | 82 | HMR 59 | 1.32 | 4.57 | 7.49 | 11.01 | 16.42 | 19.70 |
| | | HMR 36 | 1.77 | 4.48 | 6.28 | 8.46 | 10.99 | 12.83 |
| | | % change | -25.40 | 2.00 | 19.30 | 30.10 | 49.40 | 53.50 |
| San Luis | 83 | HMR 59 | 1.78 | 6.22 | 10.33 | 14.58 | 21.60 | 25.77 |
| | | HMR 36 | 1.78 | 4.48 | 7.21 | 10.33 | 14.12 | 16.63 |
| | | % change | 0.00 | 38.80 | 43.20 | 41.10 | 53.00 | 55.00 |
| Sweetwater | 88 | HMR 59 | 1.68 | 6.02 | 9.71 | 12.97 | 18.54 | 21.31 |
| | | HMR 36 | ----- | 6.39 | 9.74 | 14.01 | 18.95 | 21.95 |
| | | % change | | -5.80 | -0.30 | -7.40 | -2.20 | -2.90 |

**Table 10.1.** *Comparison of various California basin-average PMP depths (inches) from HMR 59 to HMR 36 for selected durations. Associated percentage changes also shown.*

| Site | mi² | Study | 1 hr | 6 hr | 12 hr | 24 hr | 48 hr | 72 hr |
|---|---|---|---|---|---|---|---|---|
| Lower Otay | 93 | HMR 59 | 1.81 | 6.35 | 10.23 | 13.66 | 19.57 | 22.45 |
| | | HMR 36 | ----- | 6.43 | 9.83 | 14.23 | 19.31 | 22.35 |
| | | % change | | -1.20 | 4.10 | -4.00 | 1.30 | 0.40 |
| Loveland | 94 | HMR 59 | 2.64 | 9.22 | 14.87 | 19.82 | 28.53 | 32.76 |
| | | HMR 36 | ----- | 7.77 | 12.35 | 18.49 | 25.55 | 29.47 |
| | | % change | | 18.70 | 20.40 | 7.20 | 11.70 | 11.20 |
| Morena | 109 | HMR 59 | 2.85 | 9.94 | 16.09 | 21.60 | 30.98 | 35.54 |
| | | HMR 36 | ----- | 7.41 | 11.93 | 18.09 | 25.16 | 29.00 |
| | | % change | | 34.10 | 34.90 | 19.40 | 23.10 | 22.60 |
| Barrett Lake | 124 | HMR 59 | 2.45 | 8.61 | 13.93 | 18.57 | 26.71 | 30.71 |
| | | HMR 36 | ----- | 7.40 | 11.79 | 17.66 | 24.42 | 28.17 |
| | | % change | | 16.40 | 18.20 | 5.20 | 9.40 | 9.00 |
| Stampede | 130 | HMR 59 | 1.73 | 5.33 | 8.42 | 13.24 | 21.18 | 24.50 |
| | | HMR 36 | ----- | 4.47 | 7.69 | 12.86 | 19.92 | 24.29 |
| | | % change | | 19.30 | 9.50 | 3.00 | 6.30 | 0.90 |
| Los Banos | 156 | HMR 59 | 1.50 | 5.37 | 9.10 | 12.58 | 18.74 | 22.46 |
| | | HMR 36 | ----- | 4.40 | 6.67 | 9.78 | 13.59 | 16.08 |
| | | % change | | 22.00 | 36.40 | 28.60 | 37.90 | 39.70 |
| Sepulveda | 156 | HMR 59 | 2.60 | 9.14 | 14.79 | 19.89 | 28.67 | 33.01 |
| | | HMR 36 | ----- | 7.04 | 11.06 | 16.35 | 22.45 | 25.96 |
| | | % change | | 29.80 | 33.70 | 21.70 | 27.70 | 27.20 |
| Hansen | 157 | HMR 59 | 3.75 | 13.19 | 21.36 | 28.72 | 41.41 | 47.68 |
| | | HMR 36 | ----- | 9.91 | 16.20 | 24.79 | 34.65 | 39.90 |
| | | % change | | 33.10 | 31.90 | 15.90 | 19.50 | 19.50 |
| Seven Oaks | 177 | HMR 59 | 3.37 | 11.86 | 19.16 | 25.71 | 37.17 | 42.75 |
| | | HMR 36 | ----- | 10.10 | 19.10 | 29.70 | 41.70 | 47.50 |
| | | % change | | 17.40 | 0.30 | -13.40 | -10.90 | -10.00 |
| El Capitan | 189 | HMR 59 | 2.41 | 8.52 | 13.77 | 18.55 | 26.80 | 30.93 |
| | | HMR 36 | ----- | 8.24 | 13.25 | 20.09 | 27.96 | 32.26 |
| | | % change | | 3.40 | 3.90 | -7.70 | -4.10 | -4.10 |
| Whiskeytown | 202 | HMR 59 | 1.85 | 7.64 | 14.28 | 20.04 | 30.54 | 37.04 |
| | | HMR 36 | ----- | 8.37 | 14.39 | 24.09 | 37.36 | 45.60 |
| | | % change | | -8.70 | -0.80 | -16.80 | -18.30 | -18.80 |

**Table 10.1.** *Comparison of various California basin-average PMP depths (inches) from HMR 59 to HMR 36 for selected durations. Associated percentage changes also shown.*

| Site | mi² | Study | 1 hr | 6 hr | 12 hr | 24 hr | 48 hr | 72 hr |
|---|---|---|---|---|---|---|---|---|
| Henshaw | 203 | HMR 59 | 2.27 | 8.00 | 12.96 | 17.44 | 25.23 | 29.13 |
| | | HMR 36 | ----- | 7.32 | 11.87 | 18.10 | 25.26 | 29.16 |
| | | % change | | 9.30 | 9.20 | -3.60 | -0.10 | -0.10 |
| Santa Fe | 248 | HMR 59 | 3.87 | 13.70 | 22.26 | 29.96 | 43.41 | 47.68 |
| | | HMR 36 | ----- | 11.57 | 19.18 | 29.67 | 41.70 | 39.90 |
| | | % change | | 18.40 | 16.10 | 1.00 | 4.10 | 19.50 |
| Lake Hodges | 253 | HMR 59 | 1.64 | 5.80 | 9.38 | 12.66 | 18.35 | 21.19 |
| | | HMR 36 | ----- | 6.94 | 10.83 | 16.19 | 22.38 | 25.94 |
| | | % change | | -16.40 | -9.20 | -21.80 | -18.00 | -18.30 |
| Whittier Narrow | 307 | HMR 59 | 2,37 | 8.39 | 15.43 | 18.42 | 26.68 | 30.98 |
| | | HMR 36 | ----- | 8.09 | 12.96 | 19.62 | 27.29 | 31.57 |
| | | % change | | 3.70 | 19.10 | -6.10 | -2.20 | -1.90 |
| Bradbury | 417 | HMR 59 | 3.19 | 11.41 | 18.54 | 25.09 | 36.54 | 42.52 |
| | | HMR 36 | ----- | 10.74 | 18.18 | 28.88 | 41.67 | 48.81 |
| | | % change | | 6.20 | 2.00 | -13.10 | -12.30 | -12.90 |
| Monticello | 566 | HMR 59 | 2.26 | 8.26 | 14.07 | 19.70 | 29.51 | 35.49 |
| | | HMR 36 | ----- | 6.11 | 10.16 | 16.36 | 24.57 | 29.78 |
| | | % change | | 35.20 | 38.50 | 20.40 | 20.10 | 19.20 |
| Trinity | 692 | HMR 59 | 1.42 | 5.96 | 11.30 | 15.89 | 24.55 | 30.02 |
| | | HMR 36 | ----- | 5.53 | 9.47 | 16.54 | 25.89 | 31.68 |
| | | % change | | 7.80 | 19.30 | -3.90 | -5.20 | -5.20 |
| Santa Margarita | 714 | HMR 59 | 1.38 | 4.97 | 8.20 | 11.19 | 16.29 | 19.10 |
| | | HMR 36 | ----- | 6.01 | 9.76 | 14.88 | 20.81 | 24.19 |
| | | % change | | -17.30 | -16.00 | -24.80 | -21.70 | -21.00 |
| Clear Lake | 735 | HMR 59 | 0.95 | 3.27 | 4.53 | 6.77 | 9.81 | 11.16 |
| | | HMR 36 | ----- | 2.58 | 4.08 | 6.31 | 9.25 | 11.06 |
| | | % change | | 26.70 | 11.00 | 7.30 | 6.10 | 0.90 |
| New Melones | 904 | HMR 59 | 1.75 | 5.50 | 8.89 | 14.21 | 23.42 | 27.62 |
| | | HMR 36 | ----- | 5.80 | 10.15 | 17.02 | 26.22 | 31.85 |
| | | % change | | -5.20 | -12.40 | -16.50 | -10.70 | -13.30 |
| Auburn | 973 | HMR 59 | 2.20 | 6.90 | 11.21 | 17.72 | 29.56 | 34.64 |
| | | HMR 36 | ----- | 6.48 | 11.43 | 19.39 | 30.25 | 36.99 |
| | | % change | | 6.48 | -1.90 | -8.61 | -2.28 | -6.35 |

**Table 10.1.** *Comparison of various California basin-average PMP depths (inches) from HMR 59 to HMR 36 for selected durations. Associated percentage changes also shown.*

| Site | mi² | Study | 1 hr | 6 hr | 12 hr | 24 hr | 48 hr | 72 hr |
|---|---|---|---|---|---|---|---|---|
| Twitchell | 1135 | HMR 59 | 1.24 | 4.70 | 7.90 | 10.97 | 16.24 | 19.06 |
| | | HMR 36 | ----- | 6.08 | 10.20 | 16.12 | 23.25 | 27.42 |
| | | % change | | -22.70 | -22.50 | -31.90 | -30.20 | -30.50 |
| Friant | 1591 | HMR 59 | 1.68 | 5.28 | 8.62 | 13.98 | 23.13 | 27.33 |
| | | HMR 36 | ----- | 5.31 | 9.35 | 15.60 | 23.70 | 28.56 |
| | | % change | | -0.60 | -7.80 | -10.40 | -2.40 | -4.30 |
| Folsom | 1861 | HMR 59 | 1.68 | 5.47 | 8.95 | 14.56 | 23.84 | 28.57 |
| | | HMR 36 | ----- | 5.68 | 9.90 | 16.64 | 25.75 | 31.48 |
| | | % change | | -3.70 | -9.60 | -12.50 | -7.40 | -9.20 |
| Prado Dam | 2245 | HMR 59 | 1.37 | 5.24 | 8.75 | 12.19 | 18.04 | 21.36 |
| | | HMR 36 | ----- | 5.60 | 10.60 | 16.50 | 23.10 | 26.30 |
| | | % change | | -6.40 | -17.50 | -26.10 | -21.90 | -18.80 |
| Shasta | 3027 | HMR 59 | 1.27 | 4.50 | 7.85 | 12.29 | 20.02 | 24.32 |
| | | HMR 36 | ----- | 5.36 | 9.69 | 16.64 | 26.15 | 32.09 |
| | | % change | | -16.00 | -19.00 | -26.10 | -23.40 | -24.20 |

**Table 10.2.** *Total percentage change in all drainages from Table 10.1 for each duration (HMR 59 vs. HMR 36). Negative percentages indicate that PMP computed from HMR 59 is less than that obtained from HMR 36.*

| | 1 hr | 6 hr | 12 hr | 24 hr | 48 hr | 72 hr |
|---|---|---|---|---|---|---|
| **Range of %** | -25 to 29 | -23 to 43 | -23 to 48 | -32 to 41 | -30 to 53 | -31 to 53 |
| **Mean %** | 2 | 9 | 10 | 0 | 4 | 4 |

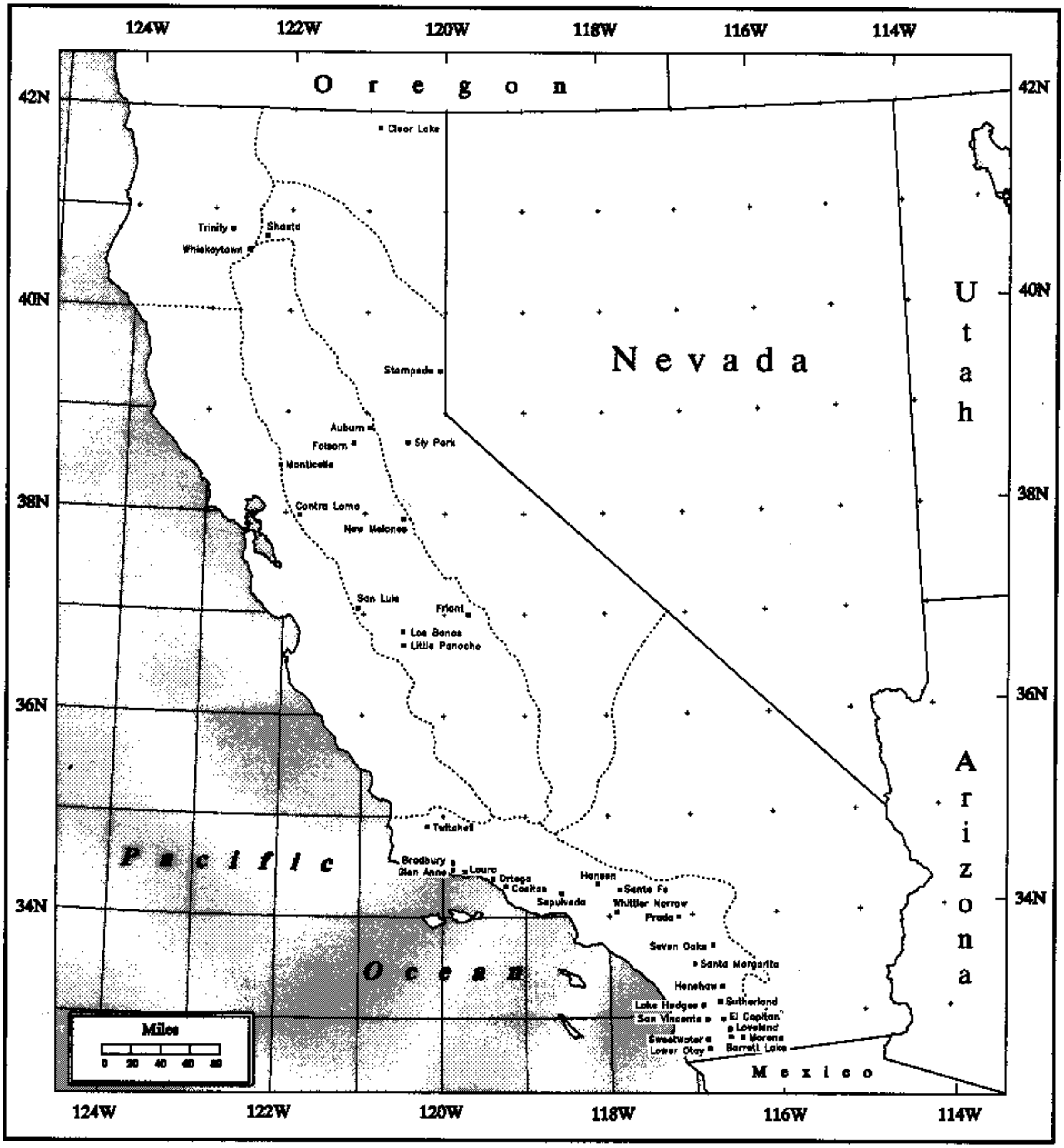



**Figure 10.1.** *Locations of basins used to compare HMR 59 and HMR 36 general-storm estimates. Dashed lines are regional DAD boundaries.*

# 11. COMPARISONS

The comparisons used to assess PMP estimates derived in this study are similar to evaluations made for previous hydrometeorological reports. However, with advanced computer technology, a more comprehensive and detailed approach is possible. In the past, comparisons between maps were made by choosing points from a grid (such as quarter degrees), manually calculating the values and then computing the differences or ratios. Now it is possible, in most cases, to determine differences or ratios by using the computer to extract values using a geographic information system (GIS). This information can be compared precisely at all locations or areas down to .08 $mi^2$ (where the raster cells have a 15-second resolution). As in recent Hydrometeorological Reports, comparisons are made between the PMP estimates and 1) 100-year precipitation frequency amounts (NOAA Atlas 2), 2) previous PMP studies for the same (HMR 36 1961) and neighboring regions (HMR 57 1994 and HMR 49 1977), 3) observed extreme rainfall, and 4) the relationship between general-storm PMP and local-storm PMP.

## 11.1 Comparison to NOAA Atlas 2

General-storm PMP was compared to the 100-year precipitation frequency analyses for 24 hours, 10 $mi^2$ from NOAA Atlas 2. As mentioned above, the ability to compare and contrast the two layers of information at every point was available and the map that represents the ratio between PMP and NOAA Atlas 2 is shown in Figure 11.1.

By definition, PMP is larger than the 100-year precipitation frequency amounts for all storm types, therefore, the ratios are always greater than one. The smallest ratio of PMP to the 100-year frequency was 1.7 which occured in the south-central Sierra Nevada mountains. Conversely, the highest ratio 4.5, was located in southeastern California near the Salton Sea, in the lee of the Sierra Nevada near Owens Valley (Figure 11.1). Most of the ratios across the state range from about 2.5 to 3.3. However, large areas of southeast California and the Central Valley are not within this range. Values reach 4.1 in the Central Valley and 4.5 in the desert southeast. In mountainous regions the trend is toward lower

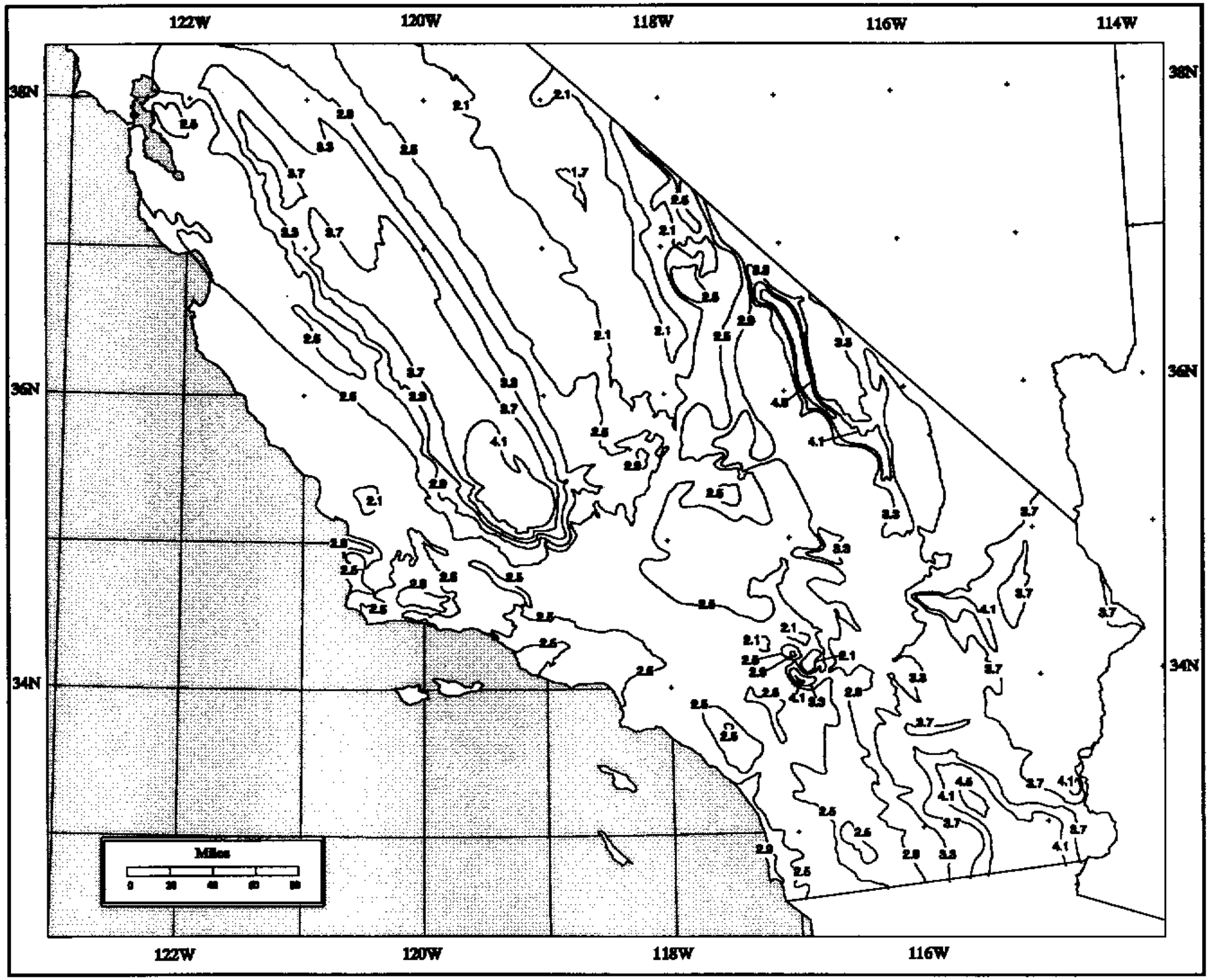



**Figure 11.1.** *Ratio of 10 mi², 24-hour PMP Index map to 100-year, 24-hour precipitation frequency analysis from NOAA Atlas 2 for California south of 38 °N (non-dimensional ratios).*

ratios where PMP estimates are less than twice as large as the 100-year precipitation frequency values.

Overall, the comparison indicates that larger ratios are in lower elevations where short-duration, convective precipitation predominates, and smaller ratios in higher elevations where general-storm, long-duration precipitation is prevalent. The precipitation over lower elevations and the desert southeast is much more sporadic with high levels of cloudburst activity. It should be noted that NOAA Atlas 2 combines all types of precipitation events together and it is impossible to know exactly which category of storm (general or local) generated the values for the 100-year frequency analyses. Nevertheless, this study has accepted the 100-year data from NOAA Atlas 2 as the best precipitation frequency information currently available, and it is used extensively throughout (see Chapters 5 and 7) as a basis for PMP development.

## 11.2 Comparison to HMR 36

PMP estimates were also compared with estimates from HMR 36. The PMP Index map was compared with a computer-calculated raster layer derived from HMR 36 at 24 hours, 10 $mi^2$. Creating a raster layer of HMR 36 was a complex process since it was based upon a 6-hour, 200-$mi^2$ convergence map and a 6-hour, 200-$mi^2$ orographic map that needed to be combined and converted to 24-hour, 10-$mi^2$ format. Other area sizes and durations were also computed and compared for specific basins. They are shown in Table 11.1 and are discussed in Section 11.3.

Instead of finding the ratio between the two studies, the difference was calculated by subtracting HMR 36 PMP from HMR 59 PMP estimates. HMR 36 does not include the entirety of California; therefore, regions to the east of the Sierra Nevada mountains and most of the desert southeast could not be compared.

The results for the 24-hour, 10-$mi^2$ comparison, shown in Figure 11.2, indicate that HMR 59 PMP estimates are anywhere from 12 inches less than to 24 inches greater than HMR 36 PMP. The area covered by positive values was several times larger than that covered by negative amounts. The areas of greatest increase were generally confined to

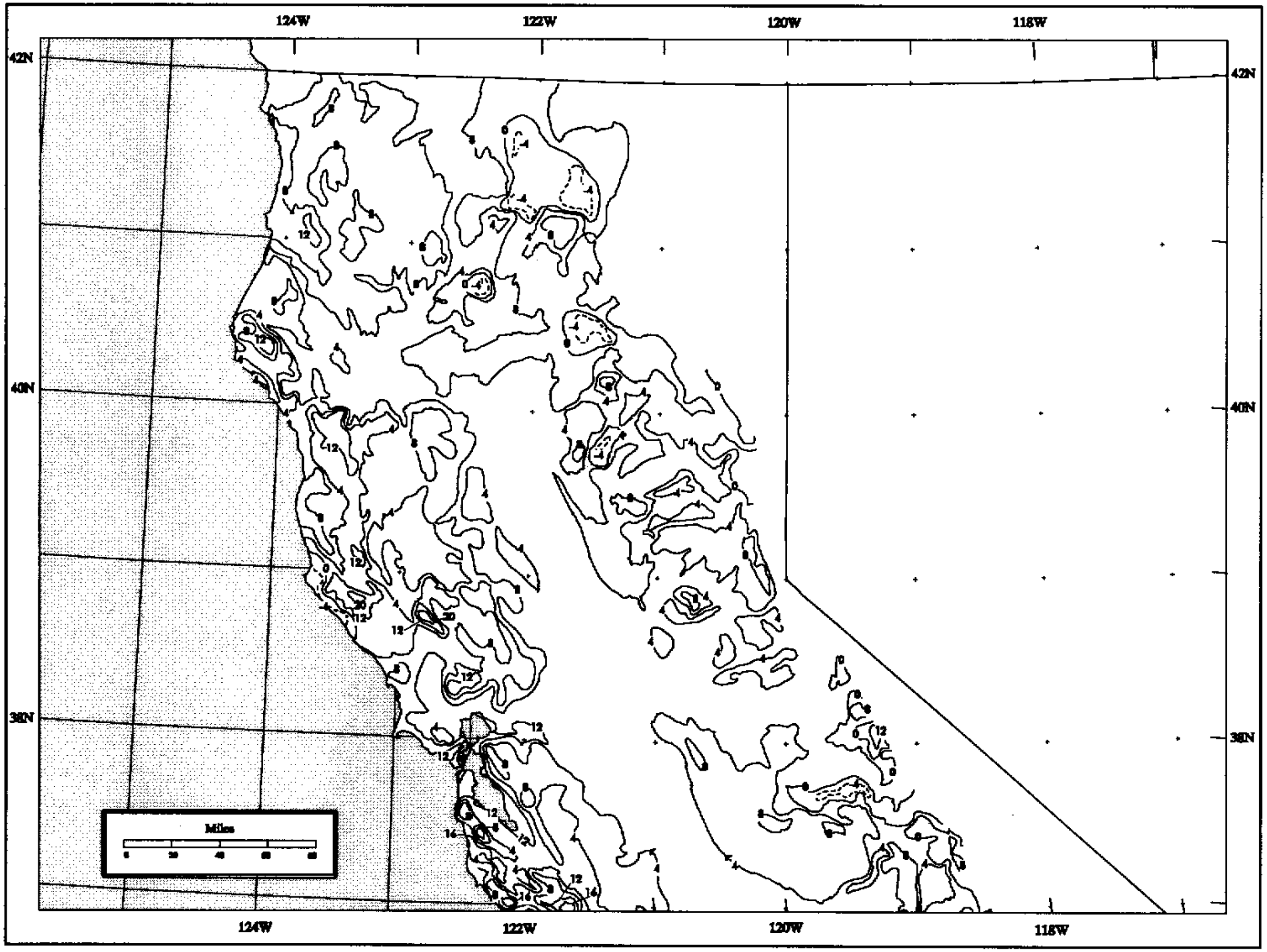



**Figure 11.2a.** *HMR 59 general-storm PMP values minus HMR 36 general-storm values at 24 hours, 10 mi² for northern California. Negative values are shown by dashed lines and positive values are solid lines. Due to the complex nature of this figure, some lines were removed for legibility.*

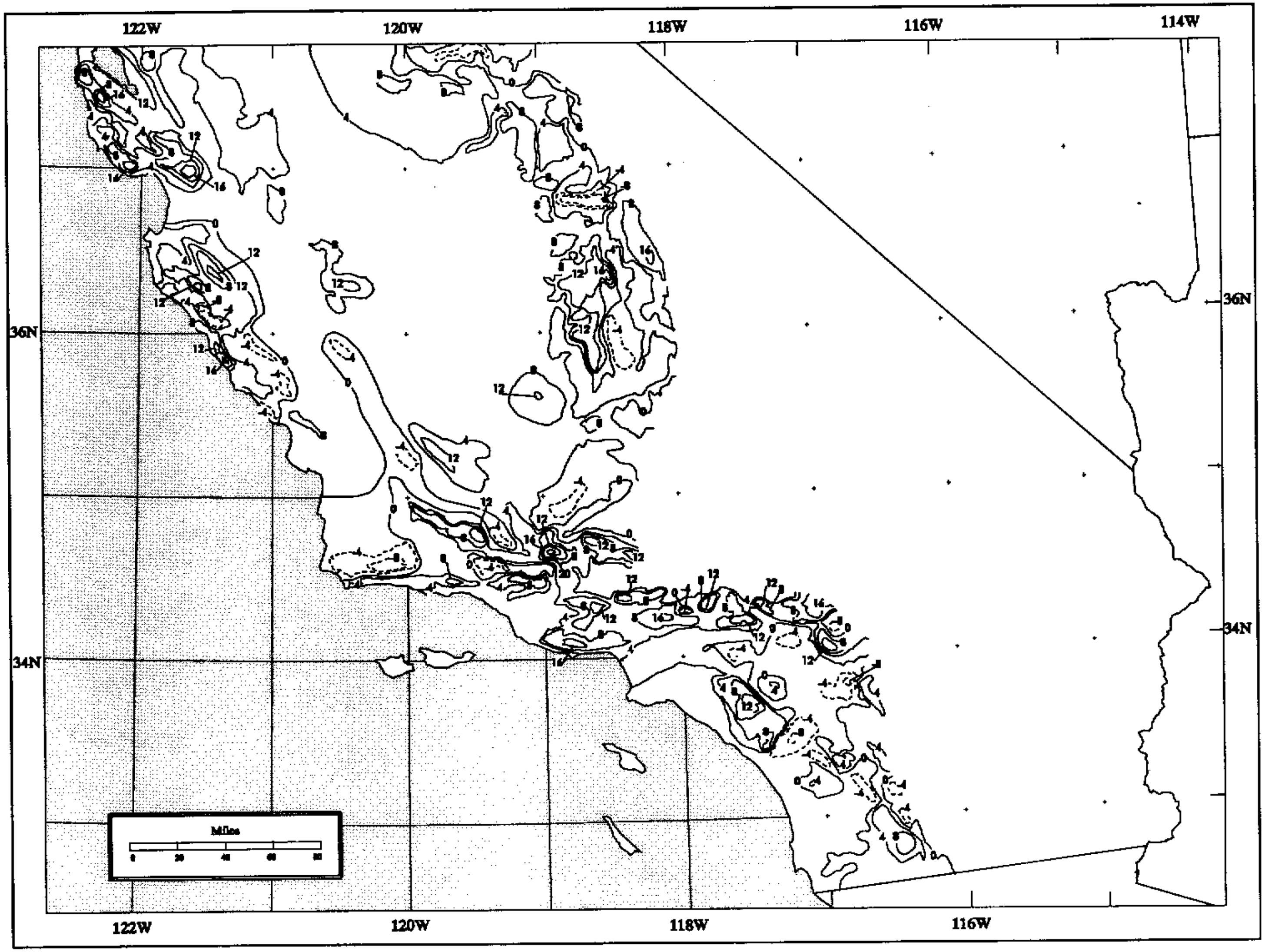



**Figure 11.2b.** *HMR 59 general-storm values minus HMR 36 general-storm values at 24 hours, 10 mi² for southern California. Negative results are shown by dashed lines and positive results are solid lines. Due to the complex nature of this figure, some lines were removed for legibility.*

orographic regions. Results showed localized increases of up to 24 inches in the San Gabriel and San Bernardino mountains from HMR 36 PMP to HMR 59 PMP. This trend of increased PMP values continues along the length of the Sierra Nevada mountains where the positive differences reach 12 inches in isolated areas. Along the Coastal range, in southern California, there are few positive differences; however, north of San Francisco most of the region had positive values reaching 24 inches in spots.

Areas with negative values, where HMR 59 PMP estimates are lower than HMR 36 estimates, are confined spatially to sheltered (downwind of major orographic regions) and non-orographic regions. There are a few valleys in the Sierra Nevada mountains where negative values reach 12 inches. Other areas of negative, but minimal differences are found in the northernmost Sierra Nevada mountains, most of the Shasta River drainage, areas just east of the Coastal mountains south of Monterey, and in portions of the non-orographic region east and south of Los Angeles.

Differences between the two reports can be attributed to several factors: to changes in technique, a longer and updated storm sample, and a better understanding of the physical mechanisms responsible for precipitation over orographic and non-orographic terrain. As HMR 59 PMP estimates are based upon the 100-year precipitation frequency, which is very detailed in mountainous regions, the complex terrain was better defined and more accurate than in HMR 36. For example, some of the negative values in the Sierra Nevada mountains occur where 100-year frequency values are relatively low compared to their surrounding values. This makes qualitative sense since these valleys are protected from moisture inflow due to their orientation, placement of other surrounding barriers, and prevailing storm inflow moisture. Most of the HMR 59 PMP increases from HMR 36, as noted previously, were in orographic regions. The explanation for this behavior again can be attributed to the use of the 100-year precipitation frequency analysis that increased the values of PMP in the higher elevations in proportion to the lower elevations. HMR 36 PMP used a mass-conservation model to create the orographic effect which created different results and less precipitation in orographic areas. The HMR 36 model was unable to describe local convergence, convection, or any of the *seeder feeder* effects that are common in mountainous areas (Browning 1980, Hobbs 1989).

## 11.3 Comparison to Extreme Rainfalls

Records from major or extreme storms listed in Chapter 2, Table 2.1 have also been compared with general-storm PMP estimates for HMR 59 and are shown in Table 11.1. The comparison is expressed as a percentage of PMP. The records are observed values from both daily and hourly stations. Again, the 24-hour, 10-$mi^2$ PMP Index map was compared, this time, with the 24-hour maximum precipitation for each station within the critical precipitation period for that storm. The critical precipitation period is defined as the portion of a storm considered most important for depth-area-duration analysis. Locations with ratios exceeding 49 percent (i.e. 24-hour maximum is one half or more of the 24-hour, 10-$mi^2$ HMR 59 PMP estimate for that point) are shown in Table 11.1. Storms without values greater than 49 percent were not included in Table 11.1.

Figure 11.3 shows 138 observations of 24-hour precipitation that exceed 49 percent of HMR 59 PMP scattered throughout California. The only region not well represented by recorded extreme rainfall is the desert Southeast. This region is under-represented due to the scarcity of stations and a lack of recorded observations. Just two storms were significant in the southeast, August 15 - 17, 1977 and July 27-29, 1984, and neither produced enough precipitation to exceed the 49-percent threshold of HMR 59 PMP.

A couple of ratios, reaching nearly 100 percent of HMR 59 PMP, did occur and are detailed below. For comparison sake, the HMR 36 PMP values are printed as well in Table 11.1. The highest ratio found from the storm list data is 92 percent of PMP at Johnsondale, California from the December 4-6, 1966 storm in the southern Sierra. Other high values include an 89 percent at Oakland Rishell Dr., near the San Francisco Bay that occurred in the October 10-14, 1962 storm, and 87 percent at Indian Rock, California just north of Lake Tahoe in the December 19-24, 1964 event.

Besides examining the data for the extreme events included in the storm list in Chapter 2, Table 2.1, maximum 24-hour precipitation values from Technical Paper No. 16 (1952) and NOAA Technical Report NWS 25 (1980) were compared. Also records from hourly and daily values, available from 1948 through 1994, were compared to HMR 59 PMP estimates. Only observations from storms not on the storm list, Chapter 2, Table 2.1, were

| **Table 11.1.** | *24-hour station precipitation from extreme storms and associated ratios for HMR 36 and HMR 59 PMP at 24 hour, 10 $mi^2$. Only ratio values greater than 49 percent are given for HMR 59.* |
|---|---|

| Storm Date | Site | Precipitation (inches) | % of HMR 36 | % of HMR 59 |
|---|---|---|---|---|
| 12/8-12/1937 | Lookout | 5.11 | <50 | 60 |
| | Trimmer Experiment Sta | 7.85 | 55 | 57 |
| | Lake City | 5.13 | <50 | 56 |
| | Montgomery Creek | 5.11 | <50 | 51 |
| 2/27-3/3/1938 | Santa Rosa Rch | 9.38 | <50 | 68 |
| 1/20-24/1943 | Hoegees Camp | 25.83 | 102 | 75 |
| | Glenn Camp | 22.93 | 77 | 75 |
| | Camp Leroy Hoegees | 26.07 | 102 | 74 |
| | Lancaster | 5.53 | NA | 69 |
| | Ontario | 8.30 | <50 | 60 |
| | Santa Anita RS | 15.41 | 65 | 56 |
| | San Gabriel Dam 2 | 22.65 | 63 | 55 |
| | Agua Dulce Canyon | 8.78 | 54 | 54 |
| | Santa Barbara | 7.34 | <50 | 52 |
| | Saugus State Hwy | 10.19 | 54 | 52 |
| | Sierra Madre | 14.47 | 62 | 52 |
| | Big Pines Park | 10.17 | 62 | 52 |
| | Salinas Dam | 8.32 | <50 | 51 |
| | Saugus Substation | 9.94 | 53 | 51 |
| | Big Santa Anita Dam | 15.36 | 62 | 51 |
| | Monrovia Falls | 15.87 | 63 | 51 |
| | San Gabriel Dam 1 | 16.97 | 59 | 51 |
| | San Gabriel Dam 1a | 17.20 | 65 | 51 |
| | Lytle Creek Headworks | 17.99 | 63 | 50 |
| 11/17-21/1950 | Mono Lake | 6.66 | NA | 59 |
| | Springville Tule Headwk | 15.04 | 74 | 54 |
| 12/21-24/1955 | Long Valley Res | 5.87 | NA | 57 |
| | Woodacre | 10.68 | <50 | 56 |
| | Mono Lake | 5.99 | NA | 53 |
| | Bowman Dam | 12.97 | 52 | 53 |
| | Donner Memorial St Park | 8.21 | 58 | 52 |
| | Topaz Lake | 4.44 | NA | 52 |
| | Paicines Ohrwall Ranch | 6.73 | 56 | 50 |

| Table 11.1. (continued) | | | | |
|---|---|---|---|---|
| **Storm Date** | **Site** | **Precipitation (inches)** | **% of HMR 36** | **% of HMR 59** |
| 10/10-14/1962 | Oakland Rishell Dr | 13.09 | 93 | 89 |
| | Radio KAHI-KAFI | 11.59 | 94 | 71 |
| | Smartsville | 9.98 | 116 | 69 |
| | Verona | 6.83 | 71 | 67 |
| | Oakland 39th Ave | 9.55 | 69 | 61 |
| | Bear River Ranch | 10.24 | 86 | 60 |
| | Hayward High School | 9.47 | <50 | 60 |
| | Country Club Center | 5.39 | <50 | 59 |
| | Aerojet Fire Dept | 6.53 | 73 | 58 |
| | Nicolaus | 5.87 | 64 | 58 |
| | Central Valley Hatchery | 6.06 | 66 | 57 |
| | Arden & Mission | 6.15 | 67 | 57 |
| | Taylorsville | 8.20 | 55 | 57 |
| | Mather AFB | 6.08 | 67 | 56 |
| | Dewey & Winding Way | 6.06 | 67 | 55 |
| | Marysville | 6.67 | 76 | 55 |
| | Milford | 6.07 | NA | 55 |
| | Westwood | 6.67 | 51 | 55 |
| | Hedge & Fruitridge | 5.72 | 62 | 54 |
| | Sierraville R S | 6.41 | <50 | 54 |
| | Jamesville | 6.22 | NA | 54 |
| | Rocklin | 6.48 | 73 | 53 |
| | Lincoln | 6.76 | 77 | 53 |
| | Cohasset 1 NNE | 11.40 | <50 | 53 |
| | Orangevale | 6.51 | 71 | 52 |
| | Coloma | 6.78 | 75 | 52 |
| | Colfax | 10.02 | 56 | 52 |
| | Town & Country Mitchell | 5.45 | 59 | 51 |
| | Applegate | 8.57 | 56 | 51 |
| | Sacramento FAA AP | 5.59 | 60 | 50 |
| | Hidden Valley Ranch | 9.49 | 69 | 50 |
| | Las Plumas | 10.40 | <50 | 50 |
| 12/19-24/1964 | Indian Rock | 10.49 | NA | 87 |
| | Lookout 3 WSW | 4.97 | NA | 58 |
| | Garberville | 12.45 | 52 | 54 |
| | Tahoe City | 7.18 | NA | 54 |
| | Donner Memorial St Park | 8.13 | 57 | 51 |
| | Harris 10 SE | 14.53 | 61 | 51 |

| Table 11.1. (continued) | | | | |
|---|---|---|---|---|
| **Storm Date** | **Site** | **Precipitation (inches)** | **% of HMR 36** | **% of HMR 59** |
| 12/4-6/1966 | Johnsondale | 16.67 | 96 | 92 |
| | Big Pine 13 SE | 6.61 | NA | 71 |
| | Independence | 6.46 | NA | 68 |
| | Greenhorn Mtn Park | 11.57 | 68 | 67 |
| | Kern River PH 3 | 7.28 | <50 | 62 |
| | Tinemaha | 5.66 | NA | 61 |
| | Camp Nelson | 15.23 | 73 | 55 |
| | Lone Pine 13 SE | 5.87 | NA | 53 |
| | Wofford Heights | 6.15 | <50 | 51 |
| | Paso Robles | 5.86 | <50 | 51 |
| | Milo 5 NE | 13.28 | 74 | 50 |
| | Springville 7 N | 9.61 | 65 | 50 |
| 1/11-18/1974 | Greenview | 6.94 | 69 | 53 |
| 1/3-5/1982 | S 96 | 9.97 | 65 | 73 |
| | S 76 | 9.87 | 72 | 72 |
| | S 390 | 23.64 | 86 | 71 |
| | S 401 | 12.92 | 79 | 70 |
| | S 99 | 9.02 | 59 | 70 |
| | S 348 | 23.31 | 79 | 69 |
| | S 382 | 11.84 | 79 | 68 |
| | S 432 | 13.11 | 80 | 67 |
| | S 167 | 13.81 | 77 | 64 |
| | S 100 | 8.59 | 56 | 63 |
| | S 443 | 11.56 | 68 | 61 |
| | S 430 | 11.60 | 65 | 60 |
| | S 124 | 14.64 | 104 | 60 |
| | S 97 | 8.31 | 57 | 60 |
| | S 368 | 10.74 | 70 | 59 |
| | S 398 | 10.88 | 66 | 59 |
| | S 1038 | 11.05 | 66 | 59 |
| | S 383 | 11.88 | 70 | 57 |
| | S 361 | 11.35 | 62 | 57 |
| | S 159 | 10.50 | 70 | 57 |
| | S 364 | 10.58 | 64 | 56 |
| | S 358 | 12.17 | 64 | 56 |
| | S 360 | 10.31 | 60 | 55 |
| | S 371 | 12.00 | 63 | 55 |
| | S 1051 | 7.54 | 52 | 55 |
| | S 98 | 7.57 | 51 | 55 |
| | S 151 | 11.72 | 64 | 55 |

| Table 11.1. (continued) | | | | |
|---|---|---|---|---|
| **Storm Date** | **Site** | **Precipitation (inches)** | **% of HMR 36** | **% of HMR 59** |
| 1/3-5/1982 cont. | S 139 | 9.57 | 64 | 55 |
| | S 478 | 10.87 | 82 | 55 |
| | S 440 | 9.83 | 58 | 54 |
| | S 350 | 19.14 | 57 | 54 |
| | S 290 | 11.34 | 55 | 54 |
| | S 74 | 7.24 | 53 | 54 |
| | S 72 | 7.24 | 52 | 54 |
| | S 169 | 9.06 | 63 | 54 |
| | S 362 | 11.43 | 63 | 53 |
| | S 354 | 19.63 | 56 | 53 |
| | S 126 | 7.11 | 53 | 53 |
| | S 130 | 12.29 | 61 | 53 |
| | S 128 | 10.93 | 54 | 53 |
| | S 140 | 8.88 | 61 | 53 |
| | S 365 | 12.35 | 66 | 52 |
| | S 431 | 15.76 | 66 | 51 |
| | S 185 | 6.28 | <50 | 51 |
| | S 120 | 9.31 | 59 | 51 |
| | S 429 | 9.05 | 53 | 50 |
| | S 428 | 16.77 | 63 | 50 |
| | S 372 | 20.95 | 62 | 50 |
| | S 154 | 11.38 | 62 | 50 |
| | S 413 | 9.83 | 61 | 50 |
| 2/14-19/1986 | Bucks Lake | 17.65 | 69 | 63 |
| | Four Trees | 17.82 | <50 | 59 |
| | Atlas Road | 16.35 | 103 | 56 |
| | Sagehen Creek | 6.97 | 52 | 50 |

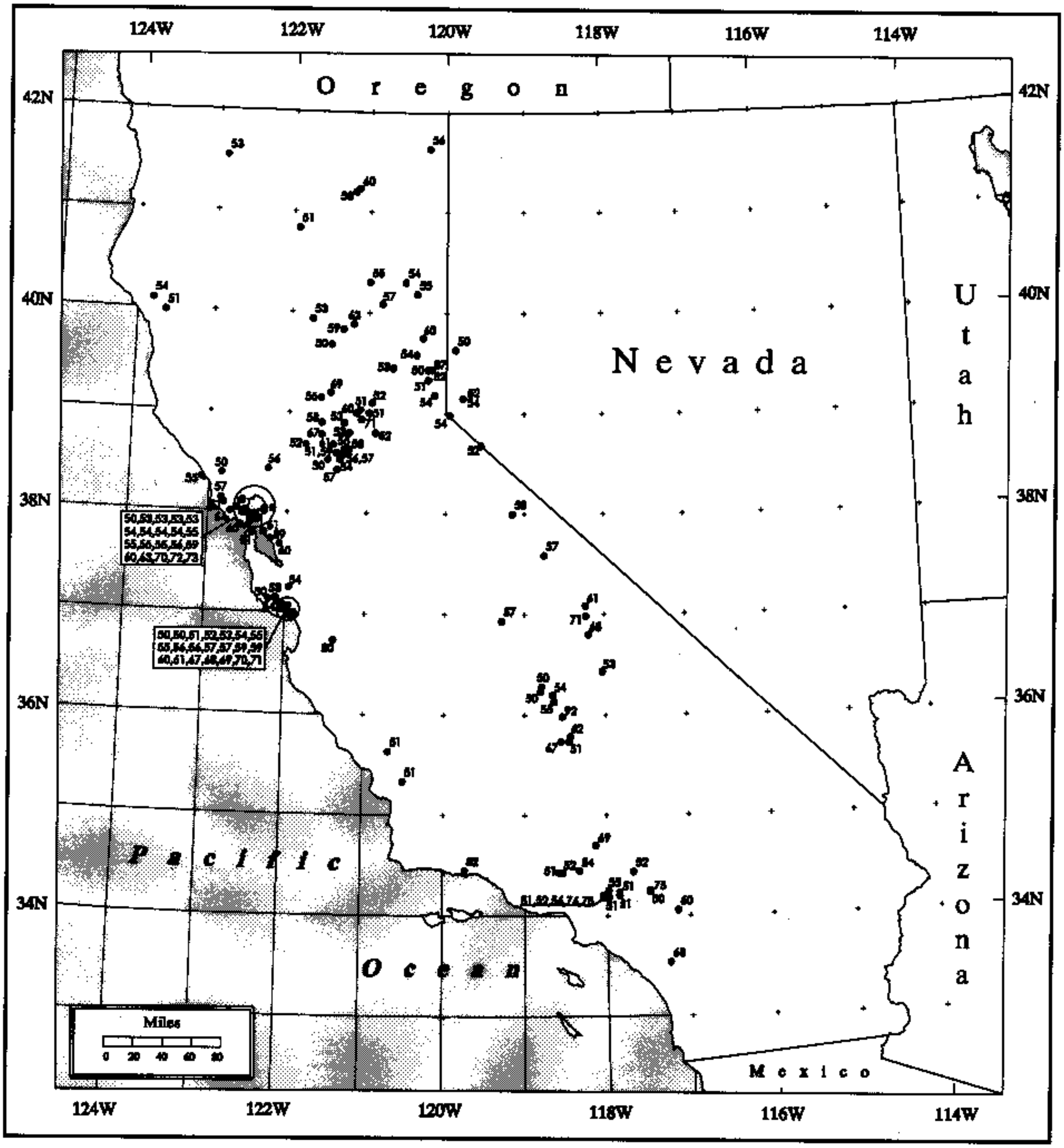



**Figure 11.3.** *Comparison between maximum point, 24-hour storm precipitation and general-storm PMP estimates at 24 hours, 10 $mi^2$. The values represent the ratio of storm precipitation to PMP. Only values greater than 49 percent of PMP are shown.*

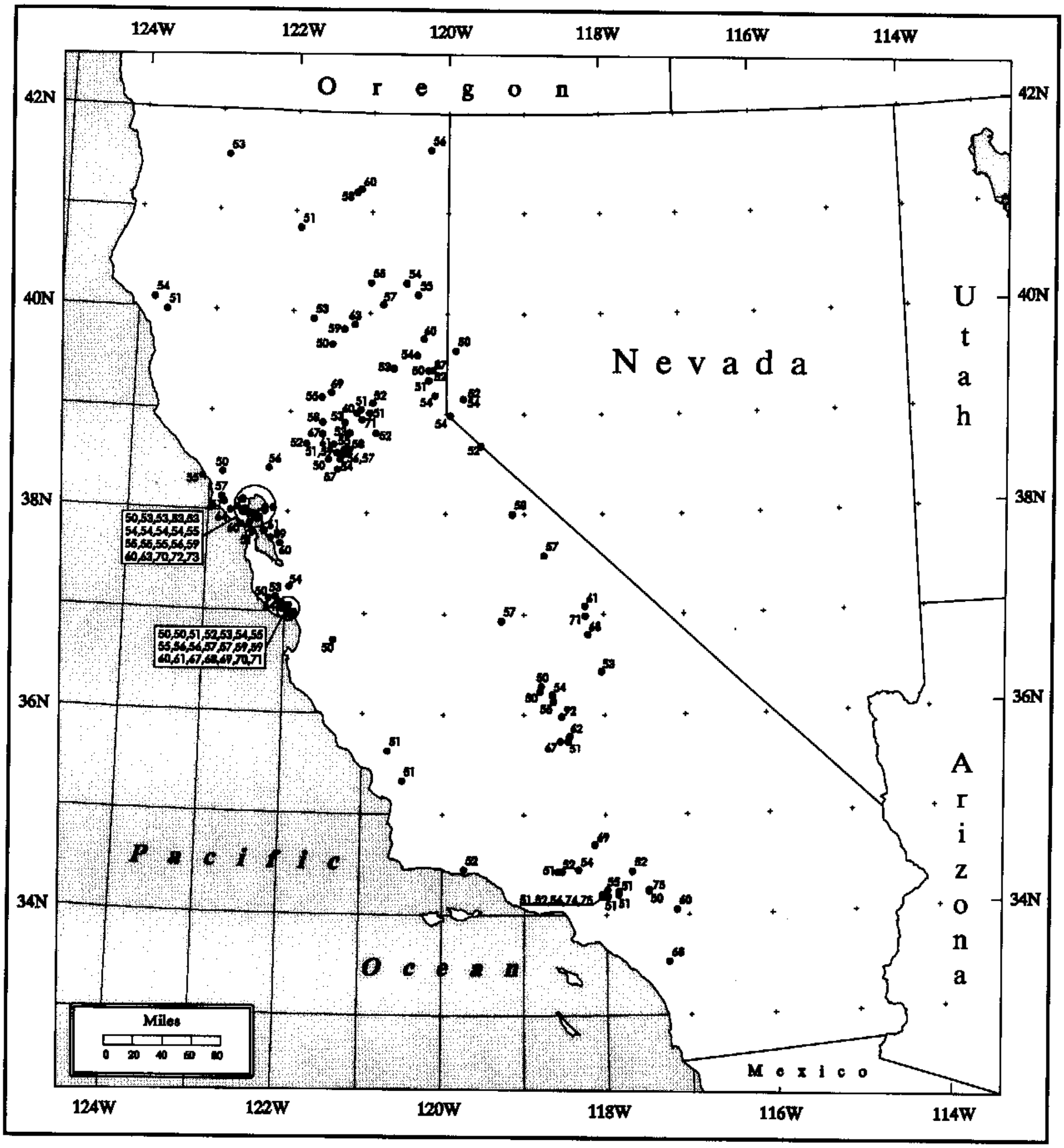



**Figure 11.3.** *Comparison between maximum point, 24-hour storm precipitation and general-storm PMP estimates at 24 hours, 10 mi². The values represent the ratio of storm precipitation to PMP. Only values greater than 49 percent of PMP are shown.*

used in this station data comparison. The most outstanding ratio from this investigation was at Ferguson Ranch, in the northern Central Valley, on December 4, 1980 where 87 percent of PMP was observed, listed in Table 11.2 and shown in Figure 11.4. This event was embedded in a large-scale heavy rainfall event. This storm was not included in Chapter 2, Table 2.1 since the precipitation associated with the storm at other surrounding stations was not nearly as significant.

Tables 11.1 and 11.2 also show the comparison of station records with HMR 36 PMP. In most cases, the percentages from HMR 36 PMP were higher than those from HMR 59. This suggests that HMR 36 PMP values are lower in most circumstances when compared directly to HMR 59 PMP. In the January 1943 storm, two stations, Hoegees Camp and Camp Leroy Hoegees, surpassed HMR 36 PMP at 102 percent. In the October 1962 storm, one station, Smartsville, registered 116 percent of PMP and two stations were in the 90 percent range. The Johnsondale storm, mentioned previously as 92 percent of HMR 59 PMP, was 96 percent of HMR 36 PMP. The January storm of 1982 had an observation of 104 percent of HMR 36 PMP and February storm of 1986 had a station report of 103 percent of HMR 36 PMP. The comparable values for HMR 59 were 60 and 56 percent respectively. It becomes clear that the revision of HMR 36 is necessary since the PMP values within it were less than those recorded in several events.

### 11.4 Comparison between General-storm and Local-storm PMP

At small area sizes (< 500 $mi^2$) and short durations (< 6 hours) local-storm PMP is often larger than general-storm PMP. Chapter 9 has the complete definition. Two sets of ratios were derived using general- and local-storm PMP values at 1 hour and 10 $mi^2$ and at 6 hours and 10 $mi^2$. Table 11.3 shows 48 grid-point locations throughout California and the associated ratios of general-storm to local-storm PMP values.

The ratios of general to local PMP values, at 1 hour and 10 $mi^2$, indicate a fairly consistent relationship, showing slightly higher ratios at the coast and lesser values inland, as seen in Figure 11.5. The exception to this tendency to decrease inland is the area of larger ratios along the central Sierra. The maximum ratio was 71 percent (not shown) along the

**Table 11.2.** *Maximum 24-hour precipitation values from stations in California. Only ratios greater than 49% of HMR 59 PMP estimates for 24-hours, 10 mi² are shown. The same stations were compared to HMR 36 where possible.*

| Site | Date | Precipitation (inches) | % of HMR 36 | % of HMR 59 |
|---|---|---|---|---|
| Ferguson Ranch | 12/4/1980 | 12.30 | 85 | 87 |
| Campo | 8/12/1891 | 11.50 | 77 | 82 |
| Nellie | 1/17/1916 | 11.24 | 70 | 77 |
| Ship Mountain | 1/12/1980 | 24.23 | 100 | 75 |
| Harrison Gulch R.S. | 12/3/1970 | 12.60 | 70 | 74 |
| Bieber | 3/31/1978 | 6.40 | NA | 72 |
| Forest Lake | 12/11/1906 | 6.07 | <50 | 71 |
| Henshaw Dam | 2/16/1927 | 14.48 | 55 | 68 |
| Boca | 3/20/1907 | 6.00 | NA | 65 |
| Sacramento | 4/20/1880 | 7.24 | 79 | 63 |
| Benton Inspect Sta. | 2/24/1969 | 5.18 | NA | 61 |
| Marysville | 12/25/1983 | 7.29 | 83 | 60 |
| Fort Ross | 11/22/1874 | 14.72 | 86 | 59 |
| White Mountain | 1/25/1967 | 6.90 | NA | 59 |
| Yreka | 1/2/1901 | 6.30 | 68 | 59 |
| Encinitas | 10/12/1889 | 6.42 | 56 | 57 |
| San Miguel | 1/18/1914 | 5.32 | <50 | 57 |
| Oakdale Woodard | 4/3/1958 | 5.72 | 75 | 56 |
| San Francisco | 12/19/1866 | 7.48 | 56 | 56 |
| McCloud | 1/23/1915 | 14.15 | 52 | 55 |
| Stirling City | 12/30/1913 | 16.23 | 59 | 55 |
| Tehachapi R.S. | 3/2/1983 | 5.30 | <50 | 55 |
| Indio | 9/24/1939 | 6.45 | NA | 54 |
| Mono Lake | 1/31/1963 | 6.13 | NA | 54 |
| Raywood Flats | 2/10/1927 | 18.87 | 67 | 54 |
| Sierraville | 12/30/1913 | 5.50 | <50 | 52 |
| Independence | 12/6/1966 | 4.95 | NA | 52 |
| Meeks Bay | 1/11/1909 | 11.99 | 55 | 52 |
| San Luis Obispo Poly. | 1/19/1969 | 7.90 | 60 | 52 |
| Lakeshore | 12/20/1955 | 15.34 | 52 | 51 |
| Platina | 12/31/1964 | 8.00 | <50 | 51 |
| Covina Temple | 2/17/1927 | 10.62 | 54 | 50 |
| Kelsey | 1/24/1983 | 9.00 | 56 | 50 |
| Upper Snowcreek | 11/23/1965 | 9.50 | 54 | 50 |

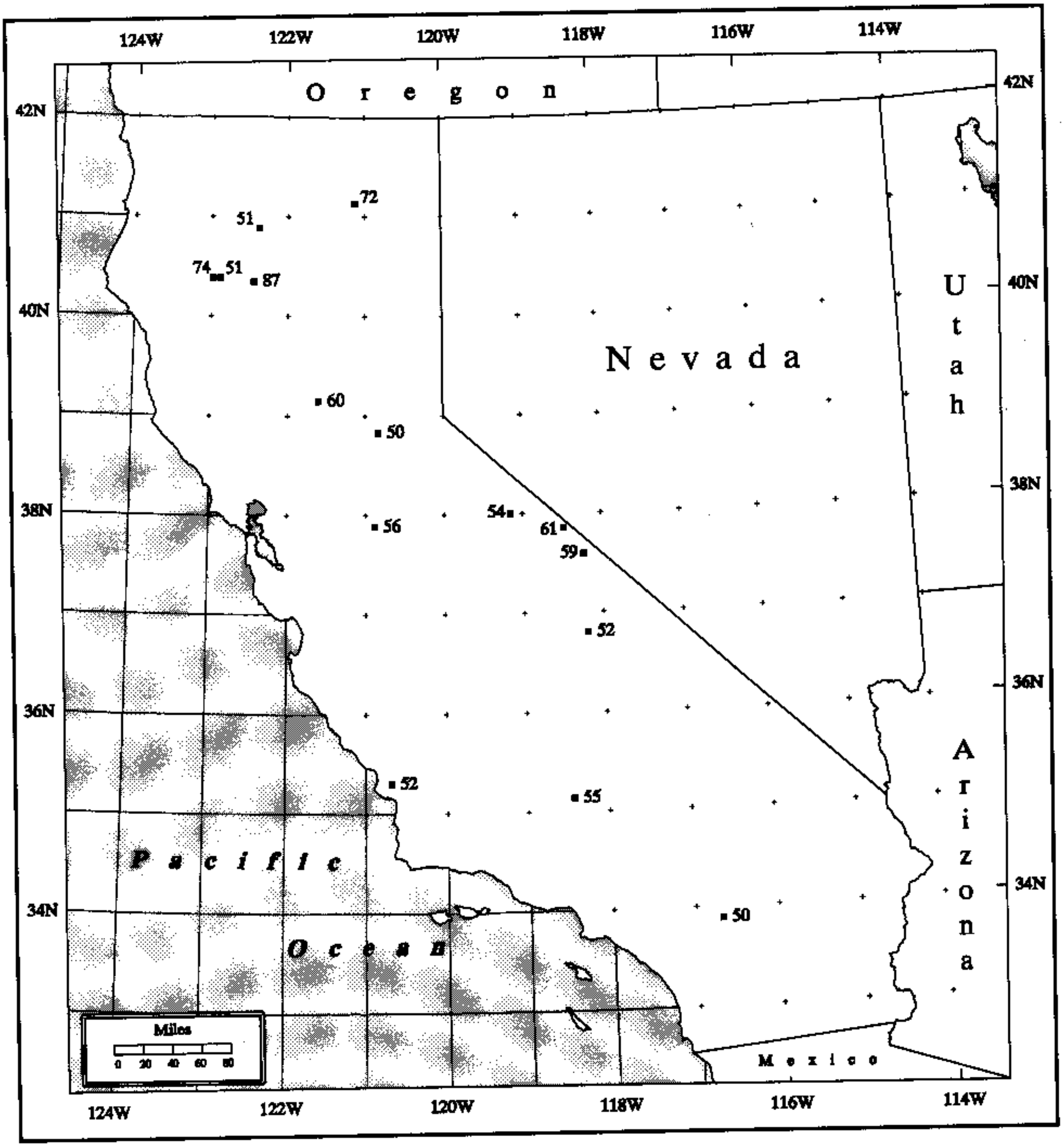



**Figure 11.4.** *Comparison between maximum recorded point rainfall at cooperative and first-order stations and general-storm PMP estimates at 24 hours, 10 mi². The values represent the ratio of historic station data to PMP. Only values greater than 49 percent of PMP are shown.*

**Table 11.3.** *Comparison of general-storm to local-storm PMP estimates (inches) for various grid-point locations at 1 and 6 hours, 10 mi².*

| Lat Lon | Local 1 hr, 10 mi² | General 1 hr, 10 mi² | General/Local 1-hr ratio | Local 6 hr, 10 mi² | General 6 hr, 10 mi² | General/Local 6-hr ratio |
|---|---|---|---|---|---|---|
| 42° -124° | 4.77 | 3.05 | 0.64 | 5.72 | 12.18 | 2.13 |
| 42° -123° | 6.03 | 1.45 | 0.24 | 7.24 | 5.87 | 0.81 |
| 42° -122° | 7.27 | 1.41 | 0.19 | 8.72 | 4.59 | 0.53 |
| 42° -121° | 7.57 | 1.34 | 0.18 | 9.08 | 4.35 | 0.48 |
| 42° -120° | 7.97 | 1.34 | 0.17 | 9.56 | 4.36 | 0.46 |
| 41° -124° | 5.02 | 2.49 | 0.50 | 6.02 | 9.98 | 1.66 |
| 41° -123° | 7.56 | 2.58 | 0.34 | 9.45 | 10.34 | 1.09 |
| 41° -122° | 9.95 | 3.58 | 0.36 | 13.93 | 10.74 | 0.77 |
| 41° -121° | 7.83 | 1.34 | 0.17 | 9.79 | 4.37 | 0.45 |
| 41° -120° | 8.01 | 1.33 | 0.17 | 9.61 | 4.34 | 0.45 |
| 40° -124° | 4.95 | 3.52 | 0.71 | 6.19 | 13.01 | 2.10 |
| 40° -123° | 7.83 | 3.10 | 0.40 | 10.18 | 11.45 | 1.12 |
| 40° -122° | 7.11 | 1.76 | 0.25 | 9.95 | 5.67 | 0.57 |
| 40° -121° | 7.65 | 2.23 | 0.29 | 9.95 | 6.68 | 0.67 |
| 40° -120° | 8.01 | 1.34 | 0.17 | 9.61 | 4.36 | 0.45 |
| 39° -123° | 5.31 | 3.20 | 0.60 | 6.90 | 11.07 | 1.60 |
| 39° -122° | 4.46 | 1.31 | 0.29 | 5.80 | 4.25 | 0.73 |
| 39° -121° | 6.30 | 2.39 | 0.38 | 8.19 | 7.18 | 0.88 |
| 39° -120° | 7.65 | 1.19 | 0.16 | 9.56 | 3.57 | 0.37 |
| 38° -123° | 4.46 | 2.21 | 0.50 | 5.80 | 7.65 | 1.32 |
| 38° -122° | 4.41 | 1.62 | 0.37 | 5.73 | 5.62 | 0.98 |
| 38° -121° | 4.32 | 1.51 | 0.35 | 5.62 | 4.88 | 0.87 |
| 38° -120° | 6.12 | 3.30 | 0.54 | 7.96 | 9.90 | 1.24 |
| 38° -119° | 7.88 | 1.29 | 0.16 | 9.85 | 3.87 | 0.39 |
| 37° -122° | 4.46 | 2.78 | 0.62 | 5.80 | 9.61 | 1.66 |